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ABSTRACT

This student text and laboratory manual is designed primarily for the non-college bound high school student. It can be adapted, however, to a wide range of abilities. It begins with an examination of the properties of nuclear radiation, develops an understanding of the fundamentals of nucleonics, and ends with an investigation of careers in areas related to nuclear radiation. Each experiment is integrated into the text. The small amount of reading material between labs is designed to bridge from one lab to another. (Author/RE)

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INTRODUCTION TO NUCLEONICS

A LABORATORY COURSE

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NUCLEAR RADIATION PROJECT STUDY

Sponsors:

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3

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Preface

The general public knows too little about radioactivity. This book is an attempt to improve this condition. Our approach is neither historic nor dogmatic. Each new concept is arrived at through a "discovery" type experiment. In this way we hope the student will lay to rest myths as he becomes better prepared for the "nuclear age".

The first five chapters are intended to provide the student with a basic understanding of nuclear radiation. The sequence is as follows: Safety and record keeping—to be followed throughout the course, detection and identification of some types of radiation, discovery of some biological effects of radiation, personal protection from radiation, and a little bit of theory.

In these times of technical advancement, it is important that young people are provided with information of existing or developing job opportunities.

After the fundamentals of the first five chapters are covered, the last four chapters are intended to make the student aware of career opportunities in nucleonics. These can be self pacing. To accomplish this we have the student engage in the type of activities he might encounter if he were employed in the field. For the student who is not interested in employment in this field, these chapters will make him aware of some of the daily applications on nuclear radiation.

With admiration and appreciation, we have drawn on the work of predecessors in the field. Some material is new and some is modified to fit our format and goals.

Insofar as we know, this is the first effort to provide a laboratory course in nuclear radiation for all secondary school students, not just the college bound or those previously interested in science.

The course has added relevance in these years of the "energy crisis", for today's students have the task of solving the many social and economic problems that we all face.

The Authors

CONTENTS

Part 1: Fundamentals of Nucleonics

Chapter I — Introduction 1

Experiments

1-1 Keeping a Record 2

Chapter II — Detection and Identification of Radiation 5

Experiments

2-1 Investigation of Discs — Are They the Same or Different? 5

2-2 The Cloud Chamber 9

2-3 The Electroscope — A Class Experiment 13

2-4 The Dosimeter 18

2-5 Scaler/Counter 24

2-6 Scaler with G-M Detector 26

2-7 Counting Statistics 29

2-8 Voltage and the Geiger-Muller Tube 33

2-9 Alpha, Beta, and Gamma Radiation or What's in a Name? 36

2-10 Magnetic Fields and Radiation 38

2-11 Solution Conductivity 41

2-12 Irradiated Solutions 46

Chapter III — Effects of Radiation 48

Experiments

3-1 Irradiation of Nonradioactive Materials 48

3-2 Radiation in our Environment 50

8

3-3 Irradiation of Flour Beetles 53

3-4 Effects of Varying Radiation Dose on Flour Beetles 54

3-5 Radiation Effects on Seeds 57

3-6 Radiation and Life 61

3-7 Safe Handling of Radioactive Liquids 63

3-8 Contamination and Disposal 67

3-9 Intake of Radioactive Phosphorous by Fish 70

3-10 Internal and External Radiation 72

Chapter IV — Protection from Radiation 81

Experiments

4-1 Radioactivity and Time #1 81

4-2 Radioactivity and Time #2 84

4-3 Radiation and Distance 87

4-4 Beta Shielding 90

4-5 Gamma Shielding 91

4-6 Back Scattering 94

4-7 Collimation 96

4-8 Amount of Radiation 97

4-9 Geometry of Radiation 101

Chapter V — A Little Radiation Physics 110

Experiments

5-1 Production of Indium Hydroxide With and Without Radioactive Indium 111

5-2 A Mini-experiment 114

5-3 Separation of Radioisotopes 118

Part 2: Applications of Nucleonics

Chapter VI — Vocational Opportunities in Nucleonics 138

Experiments

6-1 Tracers 142

Chapter VII — Industrial Applications 144

Experiments

7-1 Density Gauging 146

7-2 Thickness Gauging 148

7-3 Flaw Detection 151

7-4 Strain Gauges 153

7-5 Wear Determination 156

7-6 Detergent Efficiency 158

7-7 Flow Rate of Fluids 160

7-8 Determination of Liquid Volume in a Container 162

7-9 Liquid Level 165

7-10 Polymerization 168

7-11 Plasticizing Wood 170

7-12 Atmospheric Contamination 173

Chapter VIII — Applied Biology 175

Experiments

8-1 Nuclear Clocks 177

8-2 Food Preservation by Irradiation 181

8-3 Growth Inhibition 183

8-4 Diffusion 185

8-5 The Uptake of Carbon-14 in a Verigated Leaf 190

8-6 Phosphorous uptake in the Green Plant 196
8-7 Phosphorous and Photosynthesis 199
8-8 Colored Light and Photosynthesis 202
8-9 Effect of Low Dose Radiation on Plant Growth 205

Chapter IX — Health Services 207

Experiments

9-1 Brain Scan 209
9-2 Renal or Kidney Scanning 211
9-3 Chemical Uptake in Frogs 213
9-4 Bood Volume 217
9-5 A Model for Therapeudic Uptake 220
9-6 Outside Body Testing 223

Appendix A. Safety in the Laboratory 226
Appendix B. Periodic Chart of the Elements 227
Appendix C. Listing of Elements and Related Data 228
Appendix D. Half-Life of Selected Radioisotopes 229
Appendix E. Using Semi-logarithmic Graph Paper 231
Glossary 235

CHAPTER I

INTRODUCTION

The subject of radiation and its effects is extremely confusing to the average person. Much that appears in newspapers, magazines, and on television is reported with an eye to the sensational. They present the hazard of radiation as if its unique aspects make it impossible to understand. This tends to set it apart from all the other hazards of normal, everyday existence. The result is that the average individual feels only a highly skilled person can understand this subject. He either ignores the entire subject and the possibility of hazard to himself or, on the other hand, has an unreasonable fear of radiation injury in situations where, in fact, no real hazard exists.

The purpose of this text is to: (1) present enough of a basic understanding of nucleonics so that you may place the radiation hazard in proper perspective to the other hazards of our work day world; (2) make you aware of the peaceful uses of atomic energy; and (3) make you aware of the vocational opportunities in the application of nucleonics.

You will learn some of the fundamental concepts, and many common misconceptions will be cleared away. In order to learn these concepts, you will perform experiments and learn about radiation in much the same way as the nuclear pioneers. You could begin your study of nucleonics by learning the definitions of all the related terms in the field of physics. To really understand a term, however, you must work with the associated phenomenon until you develop a clear concept of its meaning. Even if your instructor should define a term for you, this does not necessarily mean that you would fully understand the concept, or that it would mean the same thing to you as it does to him.

In this presentation we will not necessarily precisely define our terms, but will try to use working concepts. As an analogy, we might think about the automobile. In order to safely drive the car, it is not necessary for us to completely understand how it works. We need to know how to start it, steer it, brake it, when to add gasoline, etc., but we do not need to know gear ratios, timing orders, etc.

We will develop working concepts of physical phenomena which will serve us quite well. In some cases, we may not be as precise as the physicists must be, but we will be precise enough to accomplish our purpose.

EXPERIMENT 1-1

KEEPING A RECORD

INTRODUCTION:

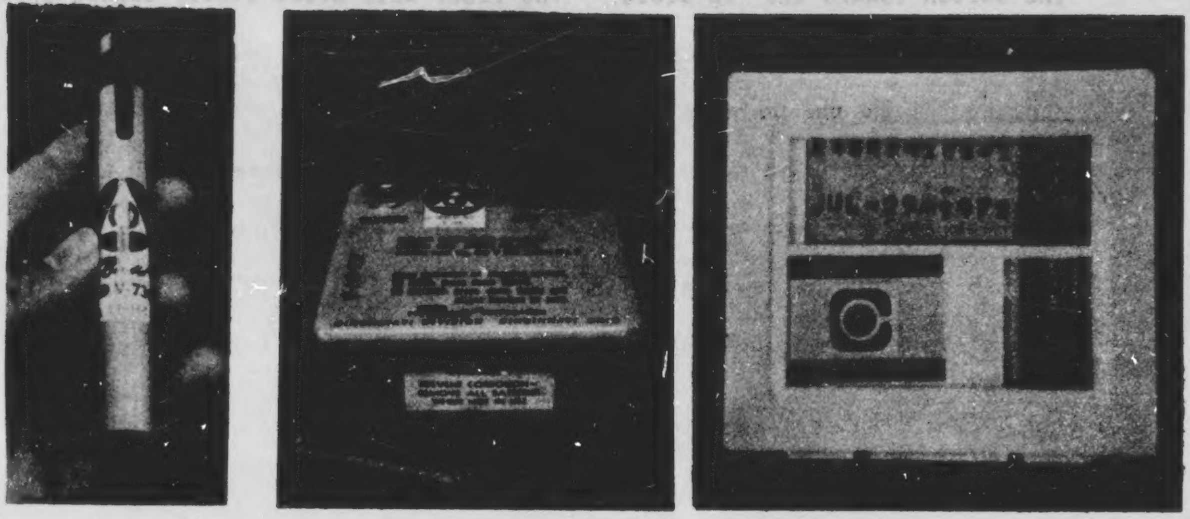
During this course we will be working with samples that are radioactive. We must keep a record of the amount of radiation that we receive. Two types of devices will be used for this purpose. The first is a film badge that will be sent each month to be read by the manufacturer. The second device is used daily and is called a dosimeter. We will study in later experiments how each of these devices work.

MATERIALS NEEDED:

1 Film badge per person
1 Dosimeter, 0-200 mr range
1 Dosimeter charger per class
1 Laboratory coat

PROCEDURE & INTERPRETATIONS:

A. The instructor will issue each of you a film badge and a dosimeter. See FIGURE 1-1. You will wear them at all times while working in the laboratory. Record their serial numbers in your lab notebook. Henceforth, you will use only those assigned to you.



Dosimeter Dosimeter Charger Film Badge

FIGURE 1-1

B. To read the dosimeter, hold it up to the light and look through the eyeplace. You may or may not see the fiber hairline, as shown in FIGURE 1-2.

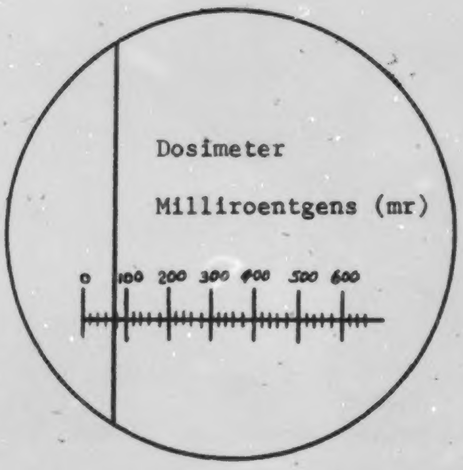


FIGURE 1- 2: Dosimeter Scale

C. To charge the dosimeter, insert the end opposite the eyepiece firmly into the contact button on the charger until the contact is depressed. While looking through the eyepiece press the switch toward the "down scale." You may observe the fiber move to the left and go below zero. Now press the switch toward the "up scale." The fiber will drift slowly toward zero. When the fiber almost reaches zero, quickly remove the dosimeter from the contact. Read the dosimeter.

D. If the fiber is below the zero line, recharge the dosimeter until the fiber is exactly zero or a little above zero. Read and record the value. This is the initial reading.

E. Make a table in your lab notebook as shown below. Use a whole page.

Film Badge Number ______________________

Dosimeter Serial Number ________________

Date	Initial Reading (mr)	Final Reading (mr)	Dose (mr)	Time (Min.)

FIGURE 1-3

F. At the end of the experiment read and record the final reading. Determine the dose and record the time that you were wearing the dosimeter.

G. Each day you will record these items in the table: date, initial reading, final reading, dose, and time. It will not be necessary to charge the dosimeter each day.

H. Notify your instructor of any large dosimeter change.

CHAPTER II

DETECTION AND IDENTIFICATION OF RADIATION

EXPERIMENT 2-1

INVESTIGATION OF DISCS - ARE THEY THE SAME OR DIFFERENT?

INTRODUCTION:

Can we use our senses or a photographic film to determine whether the discs provided contain the same or different materials?

MATERIALS NEEDED:

4 Discs labeled A, B, C, and D
X-ray film in light-proof packet
Developer solution
Fixer solution
20 ml syringe fitted with large bore needle
Cellophane or masking tape
Wash pan
Grease pencil
Straight pin

PROCEDURE & INTERPRETATIONS:

Q1 - Can you use your sense of sight, touch, smell or hearing (DON'T TASTE!) to determine whether the 4 discs contain the same or different materials? Try it.

Now take a film packet and divide it into 4 sections using a grease pencil. Mark the sections A, B, C, and D in any order (Note: Marking can be done with tape if desired.) Place each of the 4 discs in the section corresponding to its letter. See FIGURE 2-1.

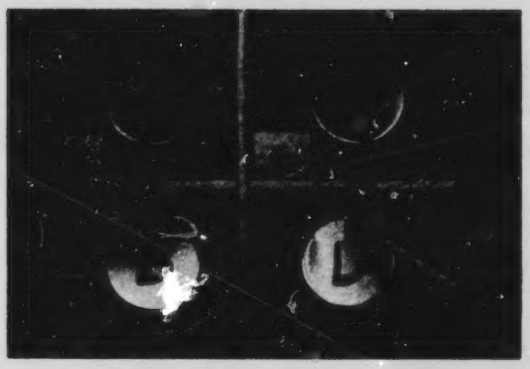


FIGURE 2-1

After about 24 hours, remove the discs and develop the film using the following procedure:

A. Take the syringe, fitted with a needle, and draw up 20 ml of developer solution.

B. Insert the needle into one of the corners of the packet being careful not to puncture both sides of the packet. See FIGURE 2-2.

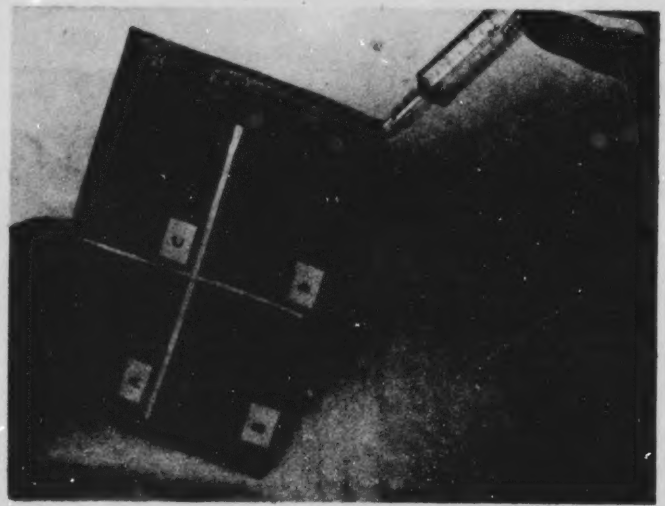


FIGURE 2-2

C. Squirt the developer into the packet and withdraw the needle. Make sure the surface around the hole is COMPLETELY DRY and then seal it with a piece of tape. Any other small holes, which develop while handling, can be sealed the same way.

D. Develop the film by holding both ends of the packet and rocking it gently back and forth so that the developer flows from end to end. After every five or six oscillations, turn the packet over and continue as before. See FIGURE 2-3.

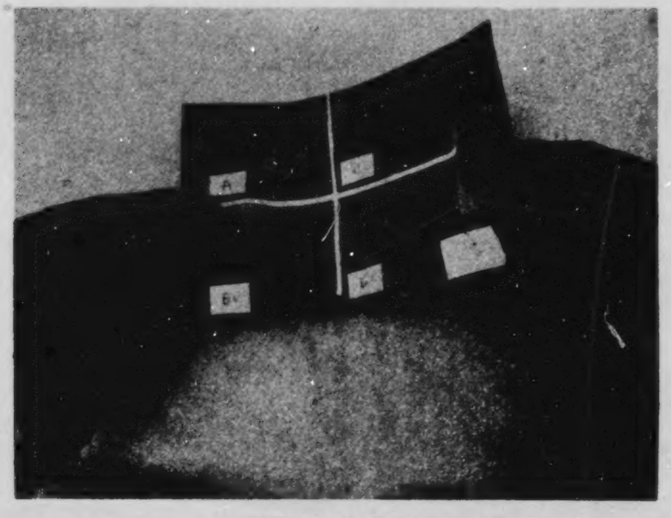


FIGURE 2-3

E. Continue the development for the time indicated below:

SOLUTION TEMPERATURE:	°F	64°	68°	72°	75°	79°
	°C	18°	20°	22°	24°	26°
DEVELOPMENT TIME (Minutes)		6	5	4	3½	3

F. After the proper time, remove the tape and re-insert the syringe needle. Hold the packet so that this end is lowest and draw off as much of the developer solution as possible. See FIGURE 2-4.

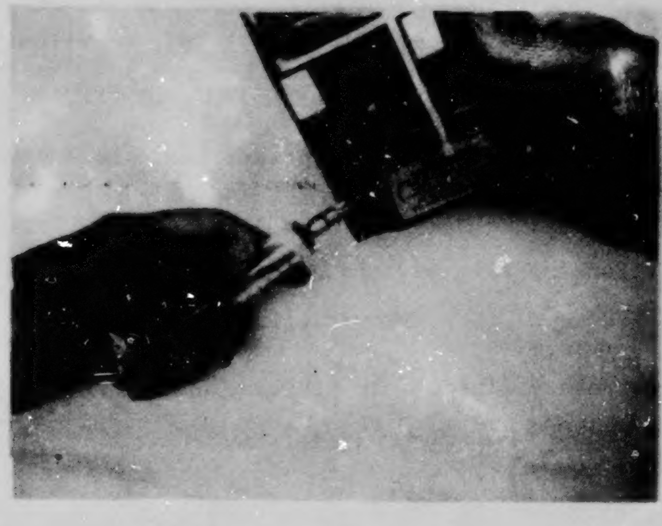


FIGURE 2-4

G. Squirt the used developer into the container provided or into the sink, as directed by your instructor.

H. Draw 20 ml of fixer into the syringe and repeat the procedure of steps C and D using the fixer in place of the developer.

I. Oscillate for about 10 minutes and then empty as in step F.

J. Before opening the packet, devise an identification code and poke pin holes through each section. This will help you identify the sections after the covering is removed.

K. Cut off one end of the packet, remove the film, and rinse it in running water for a few seconds.

L. Blot film dry using paper towels.

Q2 - Did any of the discs expose the film? Record the degree of exposure, if any, for each disc.

Q3 - If your answer to Question 2 was yes, which ones exposed it?

Q4 - If there was an exposure, was it caused by light?

Apparently something given off by some of the discs can penetrate the light-tight covering. When a process such as this occurs, the objects causing the exposure are said to be radioactive. The picture you made is called an "autoradiograph." Compare your autoradiographs with others.

Q5 - Can you determine where any of the lettered discs were placed on the autoradiographs of other groups?

Q6 - Which discs do you think are radioactive?

Q7 - Using your observations from this experiment, list as many properties of radioactivity as you can.

Q8 - What further questions or experiments are suggested by your observations in this experiment?

* * * * * * * * * * * * * * * * *

If you were to examine your autoradiograph from Experiment 2-1, using a magnifier, you might be able to observe that the exposed area consists of many tiny dots. Is it possible that the dots might be the result of individual particles, too small to be seen, striking the film? If so, is there any other method of detecting them?

Have you ever seen a vapor trail in the sky, even though the airplane which produced it was too high to be seen? Or have you seen tracks left in the snow after the animal which made the tracks is gone? When a particle passes through an area of saturated vapor, it sometimes leaves a trail of condensed vapor along its path which remains after the passage of the particle. Let's investigate to see if radioactivity might produce tracks in a similar fashion.

EXPERIMENT 2-2

THE CLOUD CHAMBER

INTRODUCTION:

Is it possible to detect the presence of radioactivity using a chamber filled with saturated vapor?

MATERIALS NEEDED:

Cloud Chamber
4 Disc sources labeled A, B, C, and D
1 Needle with a radioactive tip
Isopropyl or methyl alcohol
Dropper pipette
Dry Ice
Heavy gloves
Flat bottomed pan or beaker slightly larger in diameter than the cloud chamber
Light source such as flashlight
OPTIONAL: Polaroid camera with close-up lenses and film for camera

PROCEDURE & INTERPRETATIONS:

A. Place the dry ice on a flat surface. (CAUTION: Handle dry ice only with heavy gloves - DO NOT TOUCH)

B. If the top surface of the dry ice is not smooth and level, fill a pan or beaker with hot water and place it on the dry ice until a level depression forms.

C. Saturate the lining of the cloud chamber with alcohol.

Since time will not permit each group to test the effect of every disc, you will be assigned a disc to use and will then observe each others' cloud chambers so that you can answer all questions. Use discs as follows:

Group 1 - Disc A
Group 2 - Disc B
Group 3 - Disc C
Group 4 -Disc D
Group 5 - No disc
Group 6 - Disc A
Group 7 - Disc B
Group 8 - Disc C

Continue the above pattern if there are more than 8 groups.

D. Poke a hole (a little larger than a pin hole) in a sheet of aluminum foil which is a little larger than your assigned disc. Place the disc on the foil with the lettered side of the disc away from the hole. Fold the foil over the disc so the hole is over the center of the depression in the disc. See FIGURE 2-5. Now tape the disc to the cloud chamber so the hole in the foil is aligned with the hole in the side of the cloud chamber. See FIGURE 2-5. Cover the top hole with a piece of tape. (Groups assigned to use no disc should also tape over the side hole.)

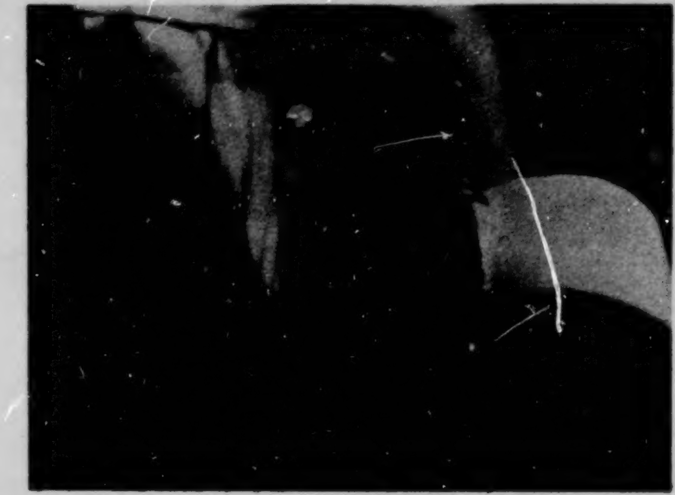


FIGURE 2-5

E. Place the assembled cloud chamber on the dry ice and allow it to cool. If necessary, use a screwdriver, or similar tool, to form a depression which will accommodate the disc. The chamber should rest flat on the dry ice.

F. After about 10 minutes, position the light source so that it will shine through the chamber from the side. After observing your cloud chamber and each of the others in the room, answer questions 1 through 4 for each disc, and for no disc.

Q1 - What do you observe? Describe and draw sketches of your observations in your lab notebook.

Q2 - If you see any tracks, do they all appear to be the same?

Q3 - If you see any tracks, do they all appear to be coming from the discs?

Q4 - Do you think individual particles are coming from any of the sources.

Q5 - Which discs appear to be radioactive on the basis of this experiment?

Q6 - Does your answer to Question 5 agree with your predictions based upon the film exposure in Experiment 2-1?

With the side hole taped closed, insert the cork, containing the needle, in the top hole of the cloud chamber. After a few minutes turn on the light and look for tracks.

Q7 - Do you observe any tracks which appear to be coming from the needle?

Q8 - If so, do the tracks appear similar to those from any of the discs?
If so, which disc(s)?

Q9 - What further questions or experiments are suggested by your observations in this experiment?

OPTIONAL: If a polaroid camera is available and time permits, try to photograph some of the cloud chamber tracks. Label them according to the needle which was being used. Tape these photographs in your lab notebook for future reference.

* * * * * * * * * * *

Thus far we have learned that we can detect radioactivity by film and by a cloud chamber. We have noted that radioactivity may be the result of invisible particles or rays given off by a radioactive source. Is it possible, if particles or rays are emitted, that they may collide with or pass very near air molecules? From earlier science courses, recall that molecules are made up of smaller particles called atoms. Each atom is composed of a heavy, dense, positively charged nucleus, which contains practically all of its weight. It is surrounded at quite some distance by a number of negatively charged electrons which have practically no weight at all. The nucleus consists of smaller particles called protons and neutrons. The protons have a positive electric charge. The neutron has no electric charge, but its weight is about the same as that of the proton. For each positively charged proton there is a negatively charged electron in an orbit at some distance from the nucleus. Thus, for a neutral atom, the number of protons and the number of electrons is equal. What would happen when an invisible particle or ray, such as we may have from a radioactive source, interacts with an atom? Since the nucleus makes up 1/100,000 of the total volume of atom and is very dense, radioactive rays do not hit the nucleus in significant amounts; and those that do hit it do not penetrate this hard ball of matter. The radioactive rays do interact with electrons that are moving about in the rest of the atomic volume. If the interaction has enough energy it may knock an electron out of an atom. The result of an atom losing an electron means that it now has more protons than electrons. It now has a net positive charge. This charged particle is called an ion. Recall that the free electron has a negative charge. The process is summarized by FIGURE 2-6.

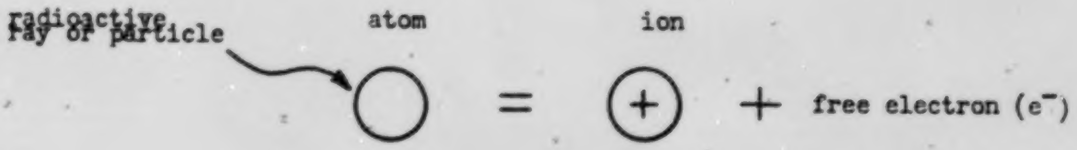


FIGURE 2-6

If this process does occur, does it suggest any other way of detecting radioactivity? Before answering this question, let's investigate a device which will detect an electric charge.

EXPERIMENT 2-3

THE ELECTROSCOPE - A CLASS EXPERIMENT

INTRODUCTION:

What happens when you run a comb through your hair or shuffle your shoes across a wool carpet? All of us have observed the effects of static electricity. In this experiment we will see if an electroscope, a device for detecting electric charges, is affected by radiation. We will do the experiment together so we can project and magnify any small changes that might occur in the electroscope. Each of you should record data and answer questions as you would with any experiment.

MATERIALS NEEDED:

1 demonstration electroscope (with wire extension on knob)
1 rubber rod
1 overhead projector with mirrors for horizontal projection (or a slide projector)
1 piece of fur
1 set of discs
1 large piece of paper taped to a wall or chalkboard
1 felt tipped pen

PROCEDURE AND INTERPRETATIONS:

Part I

Arrange the electroscope and projector so the image can be projected on the paper viewing screen. See FIGURE 2-7.

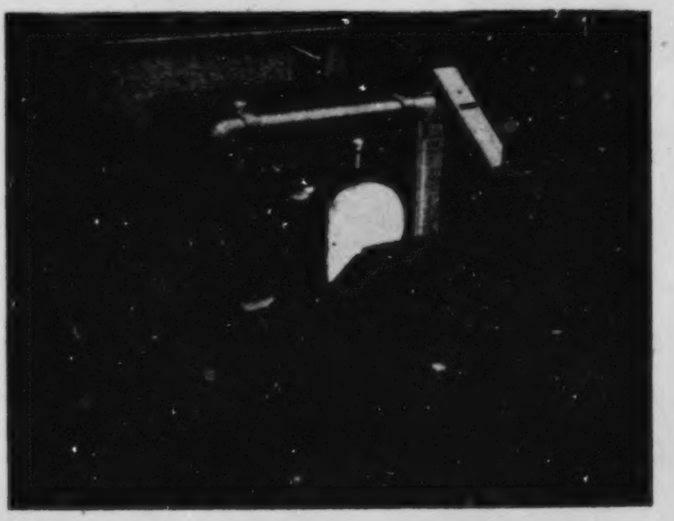


FIGURE 2-7

Charge the rubber rod by rubbing with the fur. Touch the electroscope knob.

Q1 - What do you observe?

The rubber rod has a negative electric charge caused by an excess of electrons. You may already know that like electric charges repel.

Q2 - Why did the electroscope leaves separate when the knob was touched with the charged rod?

Part II

Notice the wire extension on the electroscope knob. See FIGURE 2-8. This will aid in transferring charges to the knob.

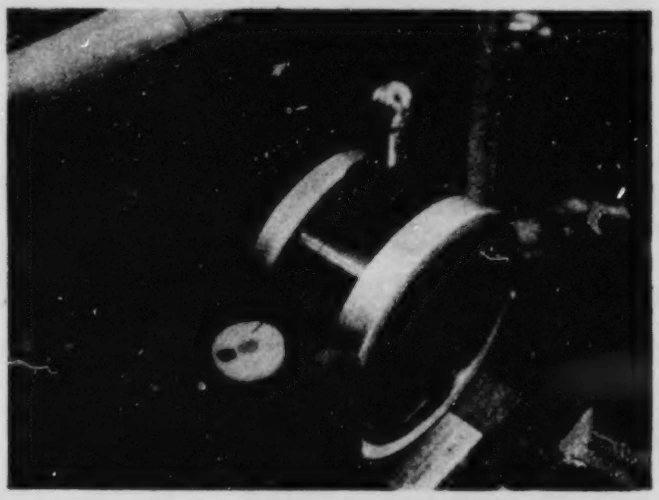


FIGURE 2-8

When the leaves are separated, we say the electroscope is charged. Charge the electroscope until the leaves extend to an angle of about 45°.

Mark the image position of the bottom edge of one of the leaves on the paper. Wait 5 minutes and mark the position of the same leaf.

Q3 - Did the position change?

Q4 - Did the change, if any, indicate a charging or discharging effect on the electroscope?

Part III

Place Disc A so it is less than $\frac{1}{4}$ inch from the tip of the wire extension on the electroscope knob. See FIGURE 2-8. Now charge the electroscope until the image of the leaf, on the paper, is in line with your original mark. Wait the same length of time as you did in Part II. Mark the position of the leaf with a dashed line.

Q5 - Did the position change? If so, how did this change compare with Part II?

Q6 - Did the change, if any, indicate a charging or discharging effect on the electroscope?

Part IV

Repeat the procedure using Disc B.

Q7 - Did the position change? If so, how did this change compare with Part II? Part III?

Q8 - Did the change, if any, indicate a charging or discharging effect on the electroscope?

Part V

Repeat the procedure using Disc C.

Q9 - Did the position change? If so, compare the change with Part II, Part III, and Part IV.

Q10- Did the change, if any, indicate a charging or discharging effect on the electroscope?

Part VI

Repeat the procedure with Disc D if you feel the need and if you have enough time.

Q11- In each of the parts, did the movement of the leaves indicate a charging or discharging effect on the electroscope?

Q12- In which part(s) did the largest discharging effect occur?

Q13- Which discs do you think produced the greatest number of charges?

* * * * * * * * * * *

In the last experiment we learned some of the basic principles of the electroscope. We will now use a miniature version of an electroscope called a dosimeter. One common form of a dosimeter resembles a pocket pen. FIGURE 2-9 shows its construction.

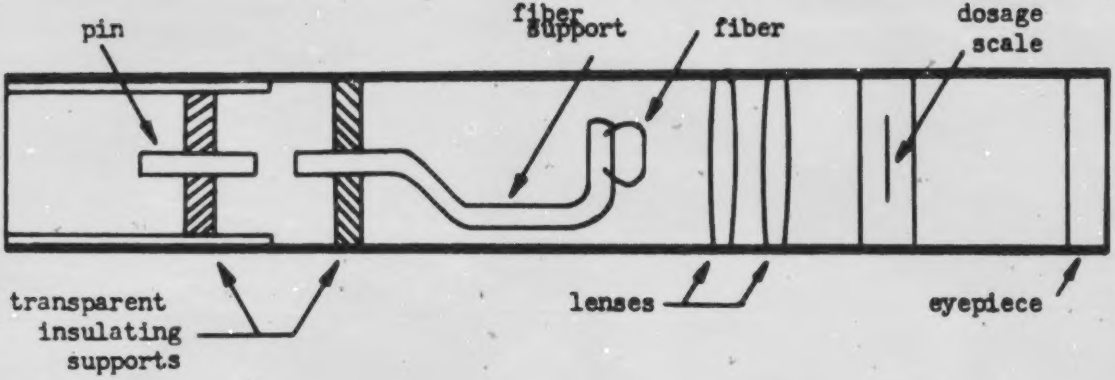

pin
fiber support
fiber
dosage scale
transparent insulating supports
lenses
eyepiece

FIGURE 2-9

A central fiber, so small it must be observed through a magnifier, is connected to the fiber support. To make connection with and charge the fiber, a bellows must be expanded which causes a pin to come in contact with the fiber support rod. This can be done by pressing the pin with a brass rod as shown in FIGURE 2-10.

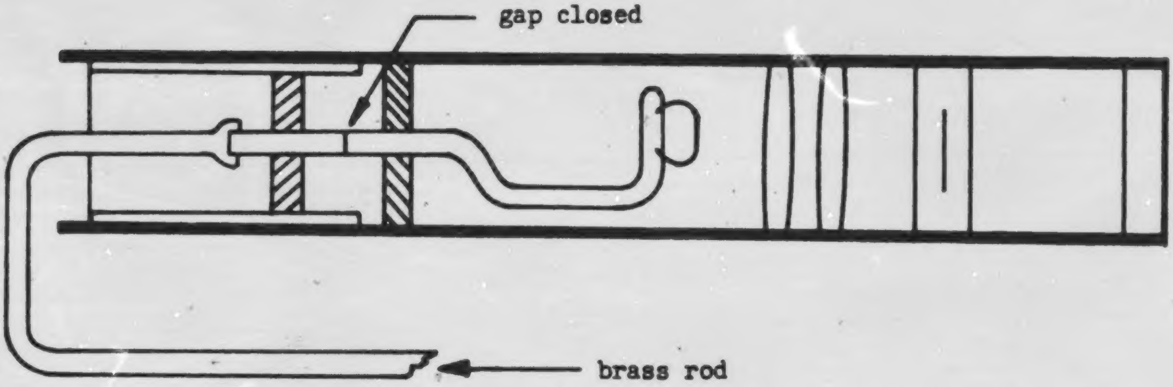

gap closed
brass rod

FIGURE 2-10

In order to charge the dosimeter you will use a dosimeter charger which provides a well controlled charge. This provides the charge which is required to "zero" the dosimeter.

EXPERIMENT 2-4

THE DOSIMETER

INTRODUCTION:

We have seen the effect of our discs on an electroscope. We have learned that a dosimeter is a miniature electroscope. Will a miniature electroscope detect radiation? In this experiment you will be working with a pocket dosimeter. See FIGURE 2-12.

MATERIALS NEEDED:

1 Set of discs
1 Dosimeter (0-200r)
1 Dosimeter (0-200mr)
1 Gammator™ or other gamma irradiator per class*
1 Dosimeter charger per class

PROCEDURE & INTERPRETATIONS:

Part I Dosimeter and Discs

In this part of the experiment each group will be assigned a task to do. When they are finished, they will "pool" their information with the other groups.

A. Groups 1, 2, 3, and 4 use 0-200mr dosimeters. Using the dosimeter charger as shown in FIGURE 2-11, charge one of your assigned dosimeters until you get a reading of zero or slightly above zero and record it. Now Group 1 place Disc A under the pocket clip as shown in FIGURE 2-12. Group 2 place Disc B in the same manner. Groups 3 and 4 place C and D in a like manner. Leave the discs clipped to the dosimeters for 10 minutes. (If discs are too thick, tape them to the dosimeter.)

---

*Gammator™ Isomedix, Incorporated, Parsippany, New Jersey.

B. Groups 5, 6, 7, and 8 use 0-200 r dosimeters. Using the dosimeter charger as shown in FIGURE 2-11, charge the dosimeter until you get a reading of zero or slightly above zero and record it. Group 5 place Disc A under the pocket clip as shown in FIGURE 2-12. Group 6 place Disc B in the same manner. Groups 7 and 8 place C and D under the clips of your dosimeters in the same way. Leave the discs clipped (or taped) to the dosimeters for 10 minutes.

Q1 - Did the dosimeter reading change? If so, how much?

Part II Dosimeter and Gammator

Groups 1-4 obtain a 0-200 r dosimeter from your instructor. Groups 5-8 use one of your 0-200 mr dosimeters.

In this portion of this experiment, you will be using a piece of equipment called a "Gammator." See FIGURE 2-12. The Gammator contains a radioactive sample whose activity we should be able to describe with the aid of the pocket dosimeter.

Look through the eyepieces of both your dosimeters.

Q2 - In what units are the scales calibrated?

Use the dosimeter charger and adjust the fiber in each dosimeter until it is zero, or slightly above zero, and record the readings. Bring your dosimeters to the Gammator. Rotate the handle of the Gammator so the chamber is open. Place both your dosimeters in the chamber. Turn the handle counterclockwise until it hits the metal stop. Estimate one or two seconds and open the chamber. Record your estimated time. Read your dosimeters and record their readings.

Q3 - What was the change in readings?

Repeat using a 0-200 r dosimeter for 10 to 15 seconds. Record the time and the change in the dosimeter reading.

Q4 - If you left the dosimeters in the Gammator for one hour, how many roentgens would they read assuming the scale would go to any value?

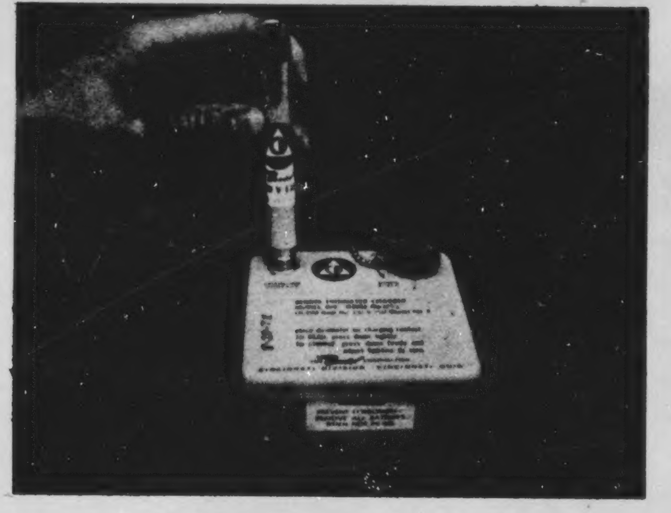


FIGURE 2-11: Dosimeter placed in a dosimeter charger

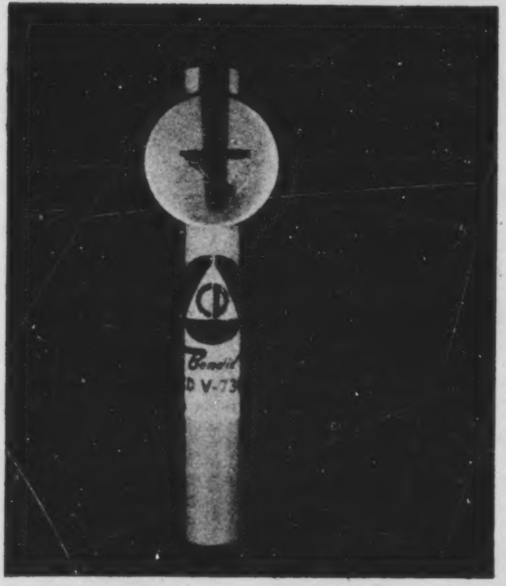


FIGURE 2-12: Dosimeter and Disc

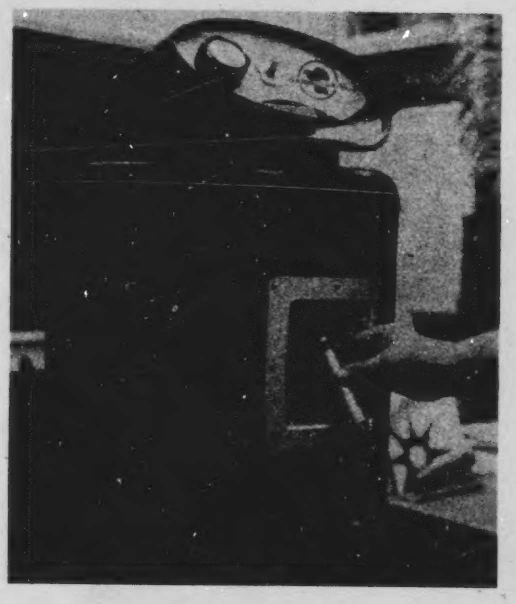


FIGURE 2-13: Gammator and Dosimeter

* * * * * * * * * * *

In the last few experiments we have learned that some of the radioactive sources affect your dosimeters The mechanism by which the charged electroscope is discharged is by the ionization of the air surrounding the electroscope See FIGURE 2-14

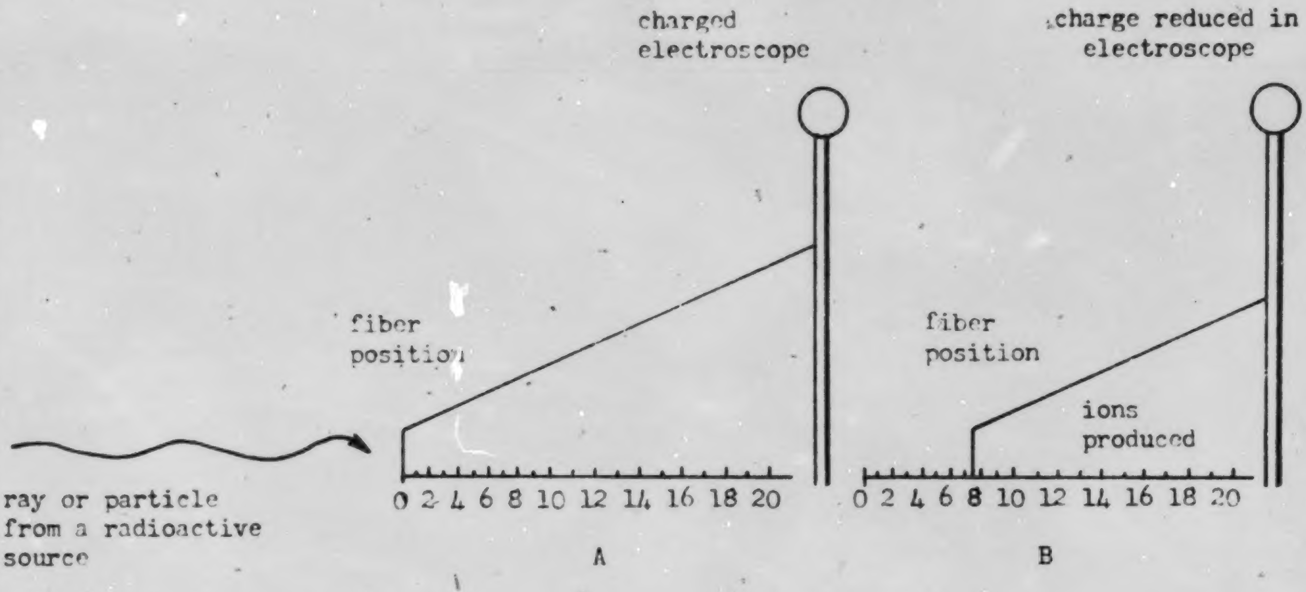

charged electroscope
charge reduced in electroscope
fiber position
fiber position
ions produced
ray or particle from a radioactive source
0 2 4 6 8 10 12 14 16 18 20
0 2 4 6 8 10 12 14 16 18 20
A
B

FIGURE 2-14

FIGURE 2-14A represents a charged electroscope (dosimeter) showing the fiber position as radiation is about to enter its chamber.

FIGURE 2-14B shows how the fiber position has changed as a result of the ions produced by the radiation

We have observed that different radioactive samples produce different effects on the dosimeter, ranging from very high readings in the Gammator to very low or "zero" readings from the discs

The units on the dosimeters are "roentgens" or "milliroentgens " Since the mechanism by which the dosimeter discharged was air ionization, it should not surprise us that the unit roentgen is defined in terms of air ionization The roentgen is a unit used in the measurement of radiation. One roentgen is defined as that quantity of radiation that will produce 2.083×10^9 (2,083,000,000) ion pairs per cubic centimeter of dry air at standard temperature and pressure (0°C and 1 atmosphere of pressure). A more precise definition is given in the glossary. Recall the ionization process discussed previously. Radiation can cause ionization of an atom by the removal of an electron. The result is a liberated negative electron and a positive ion. The two oppositely charged particles are called an ion pair. If we read 5 roentgens (5 r), then there will be $5 \times (2.083 \times 10^9)$ ion pairs produced in one cubic centimeter of dry air at standard temperature and pressure (STP).

Exercise 2-1:

If one leaves the dosimeter near a radioactive source for one hour and it changes from 0 r to 0.5 r, how many ion pairs would be produced in one cubic centimeter of dry air at standard temperature and pressure? How many roentgen units are there per hour?

When people work with radiation, most of the time they would be measuring much less than one roentgen. Thus we have a unit called a milliroentgen and 1 milliroentgen (mr) is equal to 1/1000 of 1 roentgen (r). As an example, 0.01 r would be equal to $0.01 \cancel{r} \times \frac{1000 \text{ mr}}{1 \cancel{r}} = 10$ mr.

If we wish to convert r to mr, we multiply the number of roentgens times 1000. It is sometimes necessary to convert a milliroentgen reading to roentgens. For example, if we wish to convert 10,000 mr to r, we would perform the following operation: $10{,}000 \cancel{\text{mr}} \times \frac{1 \text{ r}}{1000 \cancel{\text{mr}}} = 10$ r From this, we see that in order to convert mr to r, we divide by 1,000.

Exercise 2-2:

a. Convert 0.0005 r to mr.

b. Convert 5,000 mr to r.

c. Which is larger, 1 mr or 1 r?

Exercise 2-3:

a. If one leaves a dosimeter near a radioactive source for one hour and it changes by 10 r, how many roentgens would there be per hour?

b. If one leaves a dosimeter near a radioactive source for five hours and it changes by 10 r, how many roentgens would this be equal to per hour?

c. If one leaves a dosimeter near a radioactive source for 30 minutes and it changes by 10 r, how many roentgens would this be equivalent to per hour?

d. Which of the above would be the strongest radioactive source?

From this exercise, we can see that in order to evaluate the strength of a source it is necessary not only to know how the dosimeter reading changes but also how long we had the dosimeter near the radioactive source. To help us communicate this difference, we use a couple of terms. If we simply place a dosimeter near a radioactive source without regard to time and it changes by 10 r, we say the "dose" is 10 r. If we place the dosimeter near a radioactive source for 2 hours and it changes by 10 r, we say we have a "dose rate" of 5 r/hour (5 roentgens per one hour). Since we can also measure time in minutes and seconds, we could have a dose rate in r/hour, r/minute, r/second, mr/hour, mr/minute, or mr/second.

Since we have determined that radiation will produce ion pairs in air, can you think of another technique we might use in detecting radiation?

EXPERIMENT 2-5

SCALER/COUNTER

INTRODUCTION:

Scalers will become important instruments in the work to follow. Some observations about them should be made early. What are scalers? How do they work? What can they do? In conjunction with the scaler we will also be using a timer to determine how long an observation lasts.

MATERIALS NEEDED:

1 Electronic counter (scaler)
1 Bell switch
1 Battery (1½ v)
Hook-up wire

PROCEDURE AND INTERPRETATIONS:

PART I

The scaler has a number of controls whose settings we will define in this introductory study. List all of the controls on your instrument. Your instructor will give you a list of settings for each control. Record these in your lab notebook under the heading "settings."

Controls	Settings
1.	1.
2.	2.
3.	3.
etc.	etc.

FIGURE 2-15

Connect the battery, bell switch and wires as shown in FIGURE 2-16. Move the on and off switch of the scaler to the ON position.

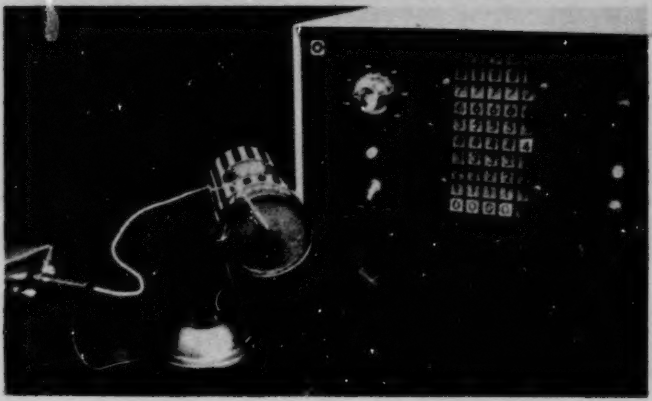


FIGURE 2-16

Be sure the high voltage switch, if present, is off or the high voltage control is set at zero. Press the bell switch and watch the scaler lights. If the lights in the first column do not change, move the count on-off switch to the ON position. (This may also be called the manual switch.) Recheck your procedure if the lights do not change as the bell switch is operated.

Q1 - Can you cause the recorded count to advance one at a time by operating the bell switch?

Q2 - Press the reset switch. What happens?

Q3 - Move the count on-off switch to the OFF position and then try to advance the count by operating the bell switch. What do you think is the purpose of the count on-off switch?

PART II

Many scalers have a test switch or test position on a switch. If your scaler has one of these, place the switch in the test position and leave it there for the remainder of this experiment. Reset the scaler to zero.

Q4 - What happens to the recorded count when the count on-off switch is operated several times?

Set the count on-off switch to stop the counting and reset the scaler. Zero the timer. Start the timer and the scaler at the same time. Stop the counting after 60 seconds.

Q5 - What number is recorded on the scaler?

Repeat this procedure several times and record the readings each time.

Q6 - By what percent do these readings differ?

Q7 - What is the average number of counts per second?

Q8 - We are using 60 cycle per second alternating current. What do you think you have measured in the above trial?

EXPERIMENT 2-6

SCALER WITH G-M DETECTOR

INTRODUCTION:

We have seen how scalers operate and how to control them. Now let's consider their applications. What can they tell us about radioactive samples?

MATERIALS NEEDED:

1 Scaler
1 Geiger-Muller tube (G-M tube)
1 Set of discs
1 Timer
1 Set aluminum shields
1 Set lead shields
1 Piece of paper
1 Calibrated Board
1 Disc Holder

PROCEDURE & INTERPRETATIONS:

PART I

Set the scaler controls at the same readings as you used in Experiment 2-5. Connect the G-M tube to the scaler's input. Turn the scaler on. Turn the high voltage on and adjust the voltage to that indicated on the G-M tube. Reset the scaler. Start the counting and the timer at the same time, and allow the scaler to count for 2 minutes. (If after about 30 seconds there is no count recorded, recheck the connections and control settings.)

Q1 - What is the recorded count after 2 minutes?

Q2 - What would this be in counts per minute?

REPEAT THIS PART AT LEAST TWO MORE TIMES.

The count recorded this way will be called "background." This should be checked and recorded at the start of each experiment using a G-M tube.

Q3 - What is the average background, in counts per minute, for these trials?

PART II

We have seen that a scaler responds to a G-M tube. How can a G-M tube, in conjunction with a scaler, tell us something about a radioactive sample? What can it tell us about that sample?

Reproduce FIGURE 2-17 in your laboratory notebook.

	A		B		C		D	
	Gross Count	Corrected Count	Gross Count	Corrected Count	Gross Count	Corrected Count	Gross Count	Corrected Count
None								
Paper								
Aluminum								
Lead								

FIGURE 2-17

Place Sample A on the calibrated board about 1 cm away from the end window of the G-M tube. Do not change the position of the tube or disc while working with Disc A. (Be sure the protective cap is removed from the window.) See FIGURE 2-18. Determine the number of counts per minute and record in your notebook.

NOTE: TO OBTAIN THE CORRECTED COUNT, SUBTRACT THE BACKGROUND COUNT FROM THE GROSS COUNT.

Place a piece of paper between the sample and the G-M tube. see FIGURE 2-19. Record the gross and the corrected counts per minute in the table. Repeat for a piece of aluminum and a piece of lead. Repeat all the above procedures for samples B, C, and D. (Be sure to complete all trials with Disc A before starting with Disc B, etc.)

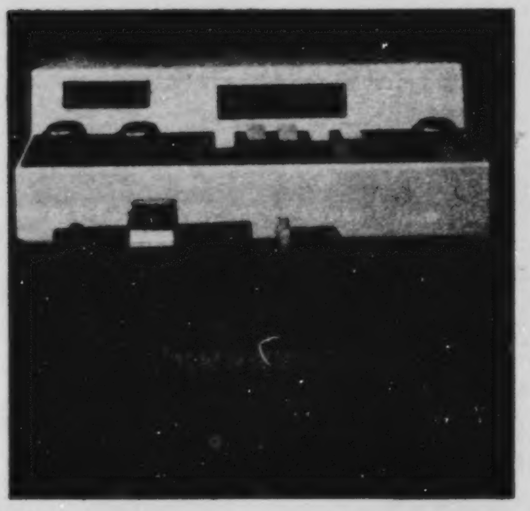


FIGURE 2-18

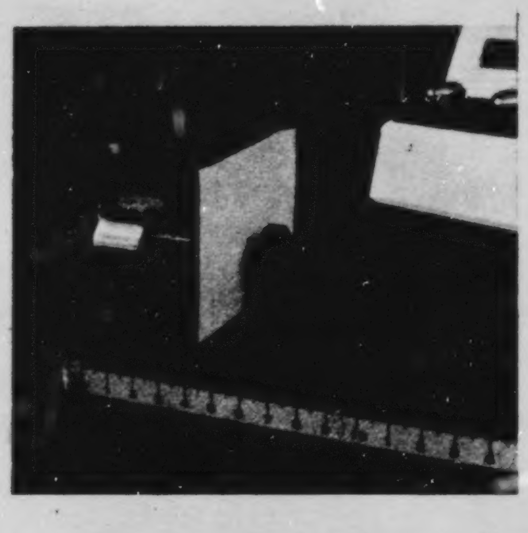


FIGURE 2-19

Q4 - For which unshielded sample was the count the greatest?

Q5 - For which unshielded sample was the count the smallest?

Q6 - What conclusion do you draw from these results?

Q7 - From which disc do you consider the radiation most penetrating?

Q8 - From which disc do you consider the radiation least penetrating?

Q9 - What leads you to this conclusion?

Q10 - Radioactive materials are used on luminous watch hands. Which radiation would you consider the safest for use on a watch hand?

Q11 - What material would be required in clothing to protect an experimenter from the radiation of Sample A? Explain your decision.

Q12 - What material would be needed for protection from Sample B? Explain.

Q13 - What material would be needed for protection from Sample C? Explain.

Q14 - What material would be needed for protection from Sample D? Explain.

Q15 - Recalling the effect of the bell switch on the scaler, what do you think happens when radiation enters the G-M tube?

Q16 - Could radiation be detected with the scaler alone?

EXPERIMENT 2-7

COUNTING STATISTICS

INTRODUCTION:

If you were to measure the activity of a radioactive source several times in succession, would you expect to obtain the same count each time? The degree of variation will be investigated by taking repeated measurements of background radiation and also on one of your discs.

MATERIALS NEEDED:

1 G-M tube and scaler

1 Calibrated board

1 Disc holder

1 Disc C

PROCEDURE & INTERPRETATIONS:

Clamp your G-M tube to the calibrated board. Take a one minute background count and record the value obtained in a data table.

Q1 - Would you expect to obtain the same value if you took another one minute count? Repeat until you have recorded a total of ten 1 minute counts.

Q2 - What is the average counts per minute?

Q3 - What is the maximum amount that any of your one minute counts varied from the average?

Q4 - What percent is this variation of the average count?

$$\% \text{ VARIATION} = \frac{\text{AMOUNT OF VARIATION}}{\text{AVERAGE COUNT}} \text{ X } 100\%$$

Place Disc C about 2 cm from the end of the G-M tube and take ten 1 minute counts.

Q5 - What is the average counts per minute?

Q6 - What is the maximum amount that any of your one minute counts varied from the average?

Q7 - What percent is the variation of the average count?

Q8 - As the count rate increases does the percent of variation change significantly? (Compare Q4 and Q7)

Q9 - Source #1 shows an activity of 500 c/m when placed in front of a G-M tube. If Source #2 were placed in the same position, how large a 1 minute count would you have to obtain before you could be fairly certain that Source #2 is stronger than Source #1?

* * * * * * * * * * * *

Experiment 2-7 should illustrate that radioactivity is a random process. Because of this, differences in two readings may be the result of this random fluctuation rather than an actual difference in the radioactive strength of the sources.

If Source #1 gives a count of 500 c/m and Source #2 a count of 1000 c/m, you can certainly conclude that Source #2 is stronger than Source #1. But what if the counts were 500 c/m and 530 c/m? Is the difference os 30 c/m significant? It is difficult to say. One way to help determine if a difference is significant is to repeat your counts several times.

Suppose you obtained the following data when you took repeated counts:

SOURCE #1 (c/m)	SOURCE #2 (c/m)
500	530
472	521
510	550
485	557
505	518
493	536

Could you now be reasonably sure that Source #2 is stronger than Source #1? There are various means of analyzing data to determine if differences are significant. The main thing for you to remember is that small differences may be due to random fluctuations. Taking counts for longer time intervals or taking repeated counts are two methods which might help you decide if a difference is significant. Remember also that a difference of 50 c/m out of a total count of 1000 is much less significant than a difference of 50 c/m out of a total count of 100.

* * * * * * * * * * * * *

In the last two experiments, you used a radiation detector called a Geiger-Muller (G-M) tube. When nuclear radiation strikes anything, it knocks electrons off the atoms that make up the material. This is the basic principle of G-M tube operation. Some materials and conditions are better for this event than others. The Geiger-Muller (G-M) tube, in its simplest form, consists of a tube into which have been sealed two metallic terminals. One terminal is the central wire and the other the outer shield. These terminals are attached to a high voltage source and filled with a suitable gas. Ordinarily no electric current will flow across the tube. When radiation enters the tube, ionization of the gas occurs. This produces a current which is amplified and can operate a counting device. See FIGURE 2-20.

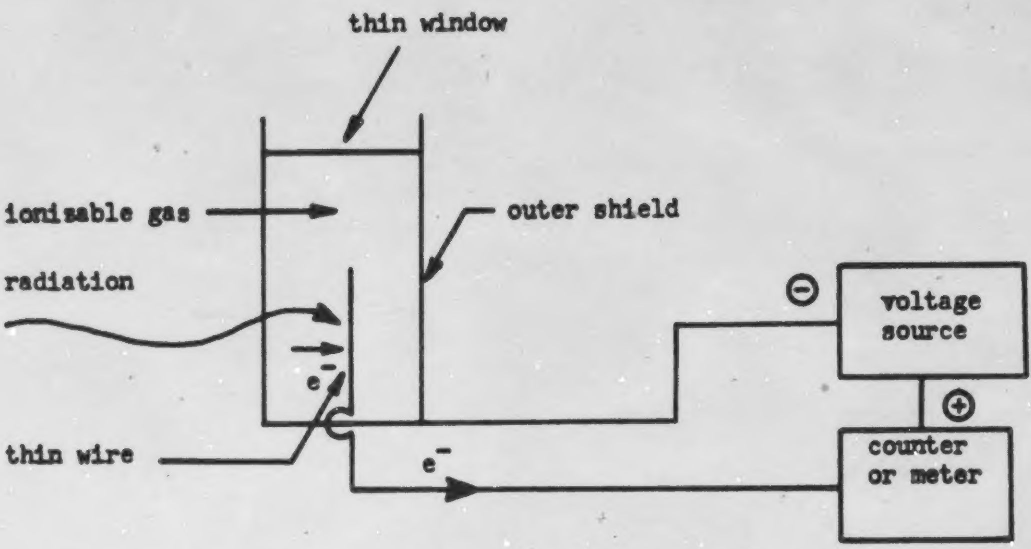

thin window
ionizable gas
outer shield
radiation
e⁻
thin wire
e⁻
⊖
voltage source
⊕
counter or meter

FIGURE 2-20

A simplified schematic diagram of a G-M tube and counting system. The e^- symbol represents an electron.

Exercise 2-4:

a. Could the window of the G-M tube be made of lead and detect radiation from Disc A? Disc B? Disc C?

b. How do you think the thickness of the G-M tube's window compares with that of a sheet of paper?

c. If you were given a G-M tube which would detect radiation from Discs B and C but not from Disc A, how would the thickness of its window compare with that of a sheet of paper?

d. We see that the window must be thin enough to permit radiation to enter the G-M tube. What other purpose does it have? See FIGURE 2-20.

e. What would happen to effectiveness of the G-M tube if a hole were punched into the window? DON'T TRY IT!!

Thus, we see that one must be very careful when handling the G-M tube.

By the manner in which the G-M detecting system works (radiation producing ions which produce a pulse of current) we see that this instrument is able to detect individual particles or rays from radioactive material. Thus, the counts/minute (pulses/minute) are an indication of the number of particles or rays which pass through the tube in one minute.

Exercise 2-5:

a. A G-M detector indicates 500 pulses or counts in two minutes while counting a given sample. How many counts would you predict in 1 minute? In four minutes?

b. In performing the same experiment using the same radioactive sample, student A reports 5,000 counts and student B reports 10,000 counts. Compare the lengths of time the counts were taken by the two students. How could they have reported their readings so we could have made an easier comparison?

The unit used in the G-M detecting system is counts/one minute (c/m).

We have discussed previously that the window of the G-M tube is very thin and, thus, it must be handled very carefully. Are there any other factors that we should consider that might affect the "life" of the G-M tube?

EXPERIMENT 2-8

VOLTAGE AND THE GEIGER-MULLER TUBE

INTRODUCTION:

Up to this time you have been setting the voltage on your G-M detector as instructed by your teacher. This knob changes the voltage applied to the G-M tube. Will the voltage affect the counts/minute? Will the voltage affect the life of the tube? Why were you told to set the instrument at a certain voltage in previous experiments?

MATERIALS NEEDED:

1 G-M detecting system (scaler with timer or count-rate meter)
1 Disc C
1 Disc holder with a clamp for G-M tube

PROCEDURE & INTERPRETATIONS:

A. Turn on the instrument and let it warm up.

B. With no source present, slowly increase the high voltage setting until you begin to get a count which is significantly above background. Record this voltage and then immediately reduce it. You have reached the continuous discharge region. In this region, the voltage applied is sufficient to ionize the gas in the tube. You will need to know this setting later in the experiment.

C. Clamp the G-M tube so it will remain in position for the entire experiment. Place Disc C about two cm away from the window of the detector.

D. Turn the count switch to the "on" or "count" position, and gradually increase the voltage until counting begins. Record this voltage. Count the sample for one minute and record the count rate in counts/minute (c/m).

E. Increase the voltage by 25 volts and take a one minute count. Record voltage and c/m. Continue taking readings at 25 volt intervals until the continuous discharge region is reached, then immediately reduce the voltage since operation in the discharge region will shorten the life of the G-M tube.

F. Record all your data in a table as shown below:

Voltage (volts)	Count Rate (c/m)

G. Plot the curve of count rate versus high voltage, labeling the axis as shown:

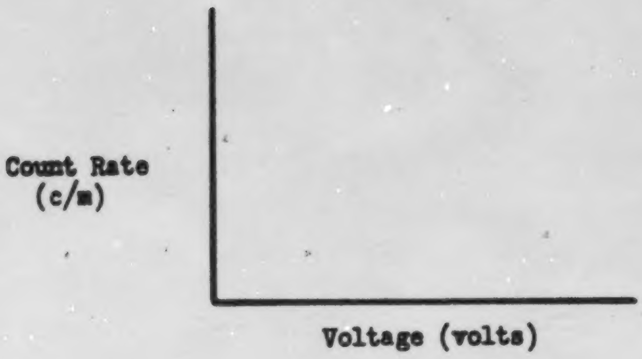


FIGURE 2-21

Q1 - Indicate on your graph the voltage at which the detector first began to detect radiation. This is called the "starting potential."

Q2 - Observe your graph. Draw dotted lines from the curve to the voltage axis indicating the area where the count rate did not change significantly with a voltage increase. This is called the "plateau."

Q3 - Indicate on your graph the voltage where the "plateau" begins. This is called the "threshold" of the detector.

Q4 - Indicate on your graph the voltage where a slight increase in the voltage caused a large increase in the count rate. This is the beginning of the "continuous discharge region."

Q5 - The proper operating voltage for the G-M tube is a value which is approximately one third of the way through the plateau. Does the voltage previously assigned to this tube fall within this range?

Q6 - When you are using the G-M detector, should the voltage be changed during an experiment? Explain.

Q7 - When the voltage setting of the G-M is below the plateau, it is said to be in the "proportional region." What difficulties could you encounter if you tried to detect radiation in this region?

EXPERIMENT 2-9

ALPHA, BETA, AND GAMMA RADIATION OR WHAT'S IN A NAME?

INTRODUCTION:

In this experiment you will be using the results of your previous experiments to summarize the characteristic properties of your radioactive samples. Using this information and the properties of alpha, beta, and gamma radiation, you will assign one of these names to each of your radioactive sources.

MATERIALS NEEDED:

Results of your previous experiments in your lab notebook.

PROCEDURE & INTERPRETATIONS:

Take a whole page in your lab notebook and divide it into four columns. Label one column A, one B, one C and the other D. Go through the results of all your previous experiments and list for each experiment the properties that you observed for your discs. List properties of Disc A in Column A, Disc B in Column B, etc.

Q1 - Which of the discs are radioactive?

Q2 - Which radioactive disc contains the most penetrating source of radioactivity? Which the least penetrating?

Q3 - Which of the radioactive sources seem to emit particles? Is there any radioactive source that does not seem to emit particles?

Q4 - If any of the discs do give off particles, which do you think emits the largest particles?

Q5 - Which of the radiations appear to have an electrical charge?

Q6 - If any of the radiations appear to have an electrical charge, which has the greatest?

Q7 - Why do you think Disc A did not expose the film?

Scientists have assigned names to various types of radiation as summarized below:

Gamma ray - symbol γ (gamma)

High energy, short wavelength electromagnetic radiation. Gamma rays are very penetrating and are best stopped or shielded against by dense materials, such as lead. Gamma rays are essentially similar to X-rays, but are usually more energetic, and are nuclear in origin.

Beta particle - symbol β (beta)

An elementary particle emitted from a nucleus during radioactive decay, with a single electrical charge and a mass equal to 1/1837 that of a proton. A negatively charged beta particle is identical to an electron. Beta particles are easily stopped by a thin sheet of metal.

Alpha particle - symbol α (alpha)

A positively charged particle emitted by certain radioactive materials. It is made up of two neutrons and two protons bound together, hence, is identical with the nucleus of a helium atom. It is the least penetrating of the three common types of radiation (alpha, beta, gamma) emitted by radioactive material, being stopped by a thin sheet of paper.

Q8 - Using the summary table above for the three common types of radiation, which radiation was Disc A producing? Disc B? Disc C? Disc D?

Q9 - What kind of radiation do you think the Gammator emits?

* * * * * * * * * * * *

Thus far we discovered some of the properties of alpha particles, beta particles, and gamma rays. We have learned that a source which emits these particles or rays is called radioactive. In order to determine the mechanism by which the electroscope discharges when beta and alpha particles are placed near it as we did in Experiment 2-3, consider the following possibilities:

1. The beta and alpha particles are charged, and hence, the electroscope is discharged due to their charge.
2. The beta and alpha particles, through collision with air molecules, cause ion pairs which discharge the electroscope.

It is possible that both the statements could be true? Recall the experiment in which you placed the dosimeter in the Gammator. All three types of radiation, including gamma which has no charge, will produce ionization and can thus discharge an electroscope.

In what other way can we learn more about the behavior of different types of radiation?

EXPERIMENT 2-10

MAGNETIC FIELDS AND RADIATION

INTRODUCTION:

It is known that a charged particle traveling through a magnetic field will be deflected. See FIGURE 2-22.

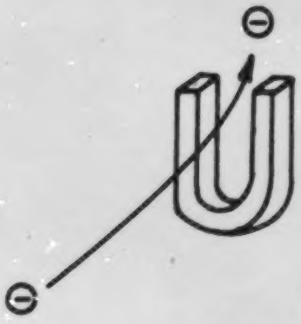


FIGURE 2-22

Will a magnetic field affect radiation?

MATERIALS NEEDED:

Disc B
Disc C
Lead shields

Geiger tube with scaler or count rate meter
3 Horseshoe magnets
Sample holding board
Timer
Millimeter ruler

PROCEDURE & INTERPRETATIONS:

PART I

Arrange the equipment and parts as shown in FIGURES 2-23, 2-24, and 2-25, and as described in the following paragraphs.

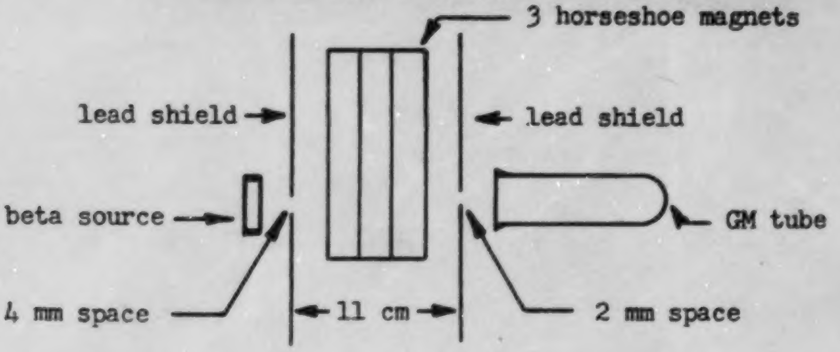

3 horseshoe magnets
lead shield
lead shield
beta source
GM tube
4 mm space
11 cm
2 mm space

FIGURE 2-23

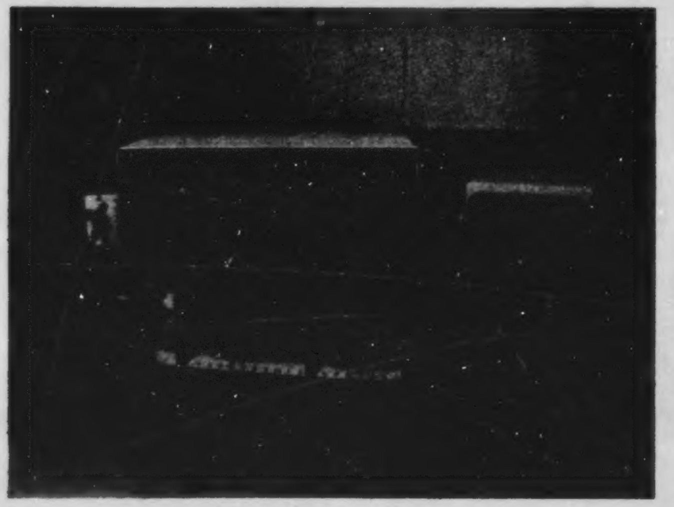


FIGURE 2-24

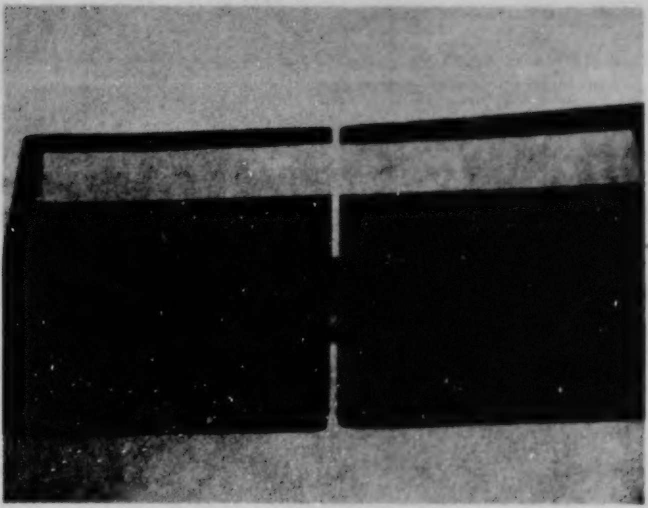


FIGURE 2-25

Tape two lead shields so the spacing between them is 4 mm. Tape two other lead shields so the spacing is 2 mm. Use one strip of tape to tape each pair together and place the tape near one edge of the shields. See FIGURE 2-25. Place the pairs of shields 11 cm apart in the holding board. Tape three horseshoe magnets between the shields as shown in FIGURE 2-24. Block the curved end of the magnets so they are level. Place the G-M tube in the clamp with the end window about 1 cm from the shields which have the 2 mm spacing. Measure and record the background count. Place the beta source about 1 cm from the shields which have the 4 mm spacing. Throughout this experiment all parts, except the magnets, should remain in these positions.

Measure and record the count with the shields, 3 magnets, and sample B in place. Remove the magnets and take another count.

Q1 - Is there evidence that the magnets, or more properly the magnetic field of the magnets, affects the beta particles?

Q2 - What, if anything, happened to the particles?

Prepare a data table for the number of magnets and the counts per minute.

Check the count (less the background) for 3, 2, 1, and 0 magnets by removing one magnet at a time. Plot a graph of counts/minute versus number of magnets.

Q3 - Describe and explain the shape of your graph.

Q4 - Can the graph indicate the amount of magnetism of the individual magnets?

PART II

Repeat the procedure prior to Question 1 for a gamma source (Disc C).

Q5 - Is there any evidence that the magnets affect gamma rays?

From the results of this experiment:

Q6 - Is a beta particle charged?

Q7 - Is a gamma ray charged?

Q8 - Would a magnetic field bend an alpha particle?

Q9 - Would it be practical to use an alpha source in this experiment? Explain. (Recall the cloud chamber experiment.)

LAB TEST FOR CHAPTER II:

You will be given an unknown object which will contain an alpha, beta, or gamma source or any combination of any of these three. For example, it could contain just beta, or it might contain beta and gamma. Your task will be to use what you have learned thus far to determine what kind of radiation(s) you get from your unknown. Keep a record of all the experiments that you perform so that you can substantiate your decision.

EXPERIMENT 2-11

SOLUTION CONDUCTIVITY

INTRODUCTION:

Do all materials behave the same when dissolved in water? Can differences be detected electrically? What happens to conduction as the amount of dissolved material is increased?

MATERIALS NEEDED:

A. C. Milliammeter (0-25 ma) (1 per class)
Power supply (0-5V A. C.) (1 per class)
Potentiometer (1 per class)
Conductivity stopper (1 per class)
Hook-up wire
Small samples of sugar, alcohol, salt (NaCl), copper sulphate, and distilled water
Distilled or deionized water
Wash bottle

PROCEDURE & INTERPRETATIONS:

Arrange the circuit as shown in FIGURE 2-26. (NOTE: one circuit can be used by the entire class.)

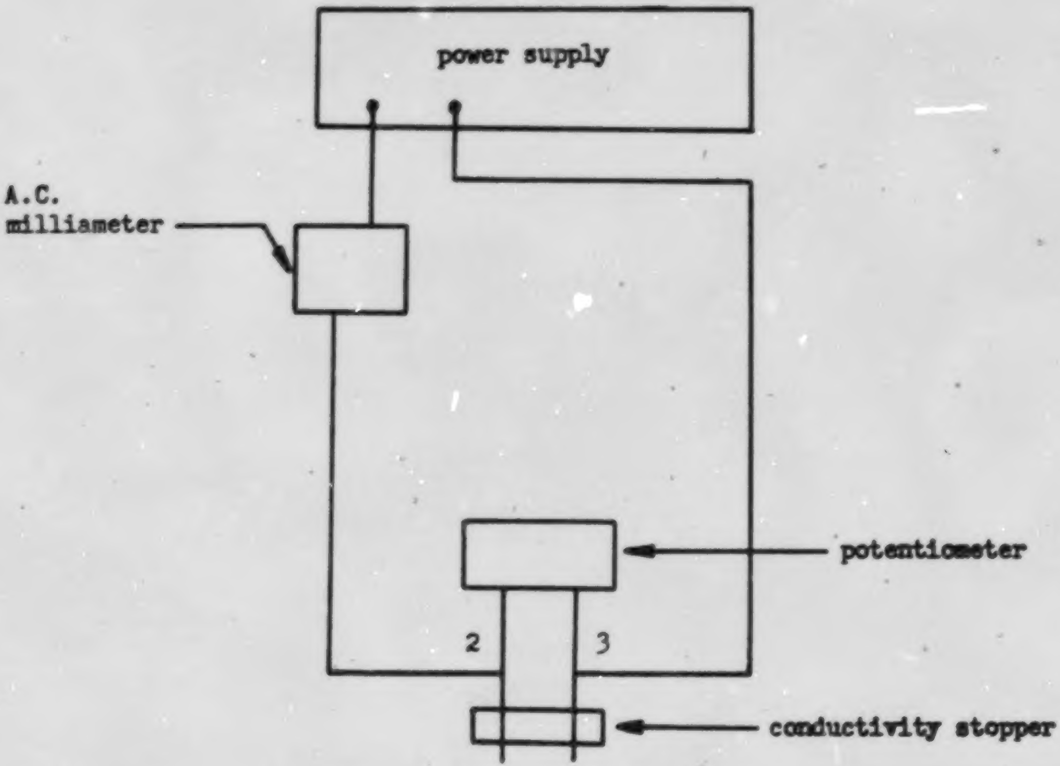

power supply
A.C.
milliameter
potentiometer
2
3
conductivity stopper

FIGURE 2-26

53

Adjust the power supply to deliver about 2 volts A.C. Put distilled water into the conductivity vial until it is about half full. Insert the conductivity stopper into the vial and invert the vial so that the liquid is in contact with the electrodes. Adjust the potentiometer until the meter reads about 10 ma. The power supply and potentiometer settings should not be changed for the rest of this experiment. (NOTE: The rest of the experiment should be done by each lab group and checked at the central circuit.) Dissolve a small amount of sugar in the water - just a pinch - and read the milliammeter.

Q1 - Did the reading on the milliammeter change? If so, by how much? (Any change in the milliammeter reading indicates a change in the conductivity.)

Discard this solution and thoroughly rinse the vial and electrodes using your wash bottle. Half fill the vial with distilled water and dissolve four drops of alcohol. Check the conductivity.

Q2 - How does this solution's conductivity compare with that of sugar?

Discard this solution and thoroughly rinse the vial and electrodes as before. Half fill the vial with distilled water. Dissolve a small amount of copper sulfate in the water - just a pinch - and check the conductivity.

Q3 - How much did the conductivity change?

Q4 - How does this solution's conductivity compare with that of sugar? Of alcohol?

Discard this solution and thoroughly rinse the vial and electrodes as before. Half fill the vial with distilled water. Dissolve a small amount of salt in the water - just a pinch - and check the conductivity.

Q5 - How much did the conductivity change?

Q6 - How does this solution's conductivity compare with that of sugar? Of alcohol? Of copper sulfate?

Discard this solution and thoroughly rinse the vial and electrodes as before.

Half fill the vial with distilled water. Check and record the conductivity of the water. Add one grain of salt. After the salt has dissolved, check and record the solution's conductivity.

Repeat these steps for two, three, four, and five grains of salt.

Q7 - How is the conductivity related to the number of grains of salt?

* * * * * * * * * * * *

In the last experiment, we found that some solutions are better conductors of electricity than others. Why?

We know that distilled water is a poor conductor; yet, if we dissolve table salt in the water, it becomes a good conductor. There must be something about the properties of salt (sodium chloride) that will cause this increase in conductivity. We have found previously that charged particles (ions) can cause an electroscope to discharge. In a way, these ions are conducting the electricity from the electroscope. Is it possible that the salt contains ions which conduct the electricity through the solution?

Solutions that conduct electricity contain ions. This will be our "model" for explaining conductivity. For example, a solution of sodium chloride (salt) contains positively charged sodium ions (Na^+) and negatively charged chloride ions (Cl^-). When we insert the electrodes into a solution and close the switch, the Na^+ drift to the negative electode and the Cl^- drift to the positive electrode. The Na^+, which are electron deficient, can accept electrons from the negative electrode. The Cl^-, which have an excess of electrons, can give them up to the positive electrode. If we multiply this process many, many times, we can see how a solution can conduct electricity. See FIGURE 2-27.

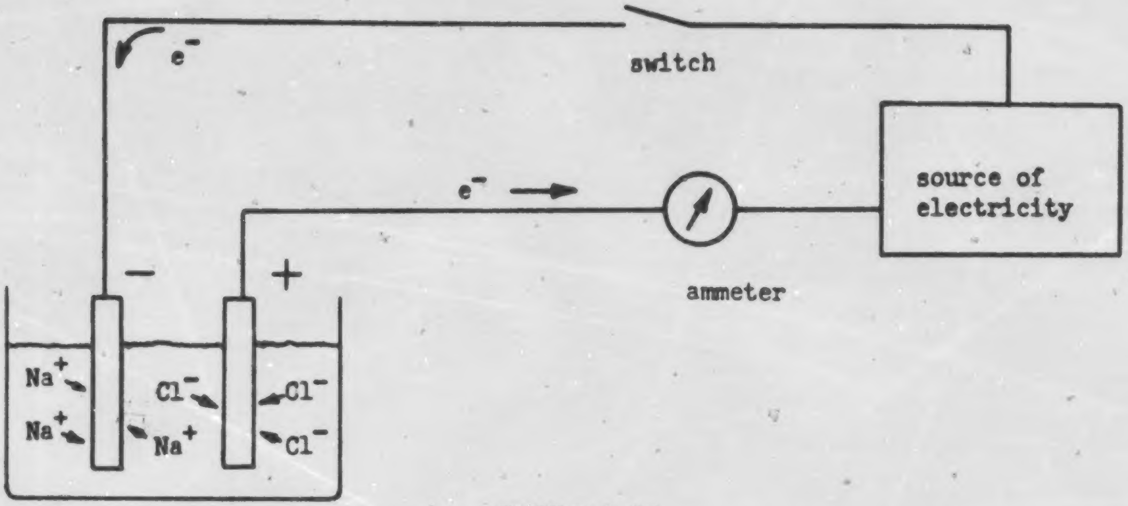


FIGURE 2-27

Exercise 2-6:

a. Apply our "model" for conducting solutions and explain why distilled water and sugar solutions were poor conductors of electricity.

b. In Experiment 2-11, why did the conductivity of the solution increase when more salt was added?

* * * * * * * * * * * *

Many chemical solutions contain ions. In the next experiment, we will be working with solutions that contain iron ions. One solution contains iron atoms that have lost two electrons and are called ferrous or Iron (II) ions (Fe^{2+}). The other solution contains iron atoms that have lost three electrons and are called ferric or Iron (III) ions (Fe^{3+}). These ions have different chemical and physical properties. By appropriate techniques Fe^{2+} can be changed to Fe^{3+} and vice versa.

If Fe^{2+} is converted to Fe^{3+}, what happens on the atomic level? Recall, Fe^{2+} has lost two electrons and Fe^{3+} has lost three electrons. Hence, if Fe^{2+}

would lose another electron it would become Fe^{3+}.

$$Fe^{2+} - e^- \longrightarrow Fe^{3+}$$

In the next experiment, we are going to investigate this reaction.

EXPERIMENT 2-12

IRRADIATED SOLUTIONS

INTRODUCTION:

Up to this point you have observed some of the ionizing effects of radiation. Gases have been ionized in electroscopes, dosimeters, and G-M tubes. Can ionization be observed otherwise? Can radiation ionize a chemical in solution? What indications of this ionization are available? Can this be detected by color change? Can it be detected electrically?

MATERIALS NEEDED:

A.C. Milliameter (0-25 ma) (1 per class)
1 Solution of ferric chloride
1 Solution of ferrous chloride
Power supply (0-5V A.C.) (1 per class)
Gammator (1 per class)
Potentiometer (1 per class)
Hydrogen peroxide
Conductivity stopper (1 per class) and vials to fit
Hook-up wires

PROCEDURE & INTERPRETATIONS:

PART I

The instructor has a sample of ferric chloride. There is also a sample of ferrous chloride (5 grams per liter of water). Be sure to keep the sample capped at all times.

Q1 - Describe the color of the ferric chloride.

Q2 - Describe the color of the ferrous chloride.

Arrange an electrical measuring system as shown in FIGURE 2-26. (See Page 42. NOTE: This is the same arrangment as the last experiment and one circuit can be used by the entire class.) Half fill a vial with ferrous chloride and insert the conductivity stopper. Set the power supply to deliver 2 volts A.C. Adjust the potentiometer until the A.C. milliameter reads 10 ma. Keep these controls unchanged for the remainder of the experiment.

Place the capped vial, along with those of the other students, in the Gammator for 10 minutes. Remove and check for conductivity.

Q3 - Was the conductivity affected by the radiation?

Q4 - Did the color of the sample change?

If no color change is observed, return the sample to the Gammator for an additional 15 or 20 minutes and observe again.

Q5 - How does the final color of the sample compare with that of the reference solution? (Ferric chloride)

Q6 - Can we accept this as evidence of ionization by gamma radiation?

Q7 - List 3 bits of evidence that radiation will cause ionization.

PART II

Discard the contents of the vial and thoroughly rinse the vial and the electrodes. Half fill the vial with ferrous chloride. Check the conductivity of the solution and record the meter reading. Add 4 drops of the hydrogen peroxide solution. Check and record the new conductivity reading.

Q8 - When hydrogen peroxide was added, did the solution's color change?

Q9 - If so, was the color change the same as for the irradiated sample?

Q10 - Did the conductivity change in a way similar to that of the irradiated sample?

Q11 - How could you use a solution of ferrous chloride to detect radiation?

CHAPTER III

EFFECTS OF RADIATION

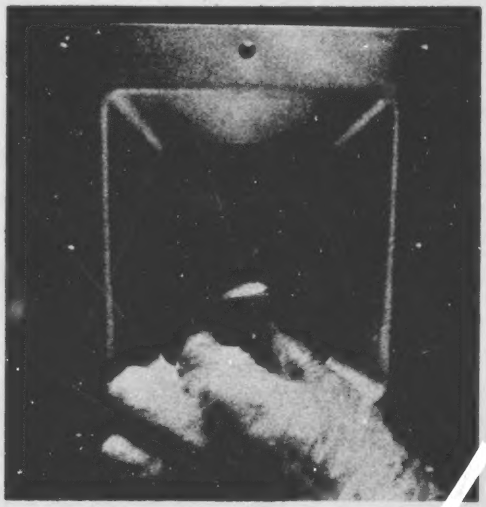
In Chapter II, we learned to detect radiation and how to measure it. We also learned that there are different kinds or types of radiation. In this chapter, we will consider the effects of radiation on other materials, both non-living and living.

EXPERIMENT 3-1

IRRADIATION OF NONRADIOACTIVE MATERIALS

INTRODUCTION:

Will materials become radioactive when exposed to high doses of radiation? Using the Gammator we can obtain massive radiation doses. In case this causes the samples to become radioactive, wear plastic gloves to handle all materials which have been in the Gammator. Exposure to radiation such as this is called irradiation.



MATERIALS NEEDED:

One sample from each of the following groups:

1. Living Organic (seeds, nuts, etc.)
2. Dead Organic (wood, cork, etc.)
3. Mineral (salt, stone, etc.)
4. Liquid (water, alcohol, etc.)
5. Metal (lead, aluminum, etc.)
6. Disc D from the radioactive sample set

End window G-M tube
Scaler
Gammator
Disposable plastic gloves

PROCEDURE & INTERPRETATIONS:

Groups 1 through 6, select a sample from the list with the same number as your group. Other groups choose 1 item each at random.

Using the end window G-M tube and scaler, determine the background count. Make certain that the samples selected from all groups will fit together into the Gammator chamber. Take an initial count on your sample using the G-M tube and scaler.

Q1 - Are any of the samples initially radioactive?

Irradiate each sample in the Gammator for a predetermined period of time. (Suggestion: 24 hours.) After that time take a background count. Then, while wearing plastic gloves, remove the samples from the Gammator and take another count on your sample.

Q2 - Have any or all of the samples become radioactive?

Q3 - Was it necessary to handle these materials with plastic gloves?

Q4 - What is the difference, if any, between food which has been irradiated with a radioactive material and food which has been contaminated with a radioactive material? (Contaminated food would have radioactive material on it or as part of it.)

Q5 - If a person eats food which has been irradiated, will he be taking radioactive material into his body?

EXPERIMENT 3-2

RADIATION IN OUR ENVIRONMENT

INTRODUCTION:

Can we eliminate all radiation to ourselves? What are the sources of radiation around us? In this experiment, we will consider some of the possible causes of background radiation.

MATERIALS NEEDED:

G-M tube
Scaler or count rate meter (portable)
mr range dosimeter (1 per group)
Dosimeter charger
Lead shields or lead bricks
High volume air sampler or vacuum cleaner (tank type)
3" x 3" screen wire square (not needed if high volume air sampler is used)
Filter paper

PROCEDURE & INTERPRETATIONS:

PART I

Before starting most radiation experiments, we take a background count. Does this radiation come from radioactive materials stored in the room? Try taking background counts in various parts of the room. (Use the same G-M tube and meter.) If you are using a count rate meter, and the rate is very low, count the clicks which you hear in a minute, rather than trying to read the scale. If possible, also take counts in other rooms or in other parts of the building. Try taking a count with the G-M tube surrounded by lead shields or lead bricks. If lead shields are used, stack several shields together to form bundles about 1 cm thick. Tape each bundle together. Tape 6 bundles together to form an enclosure for the G-M tube. See FIGURE 3-1.

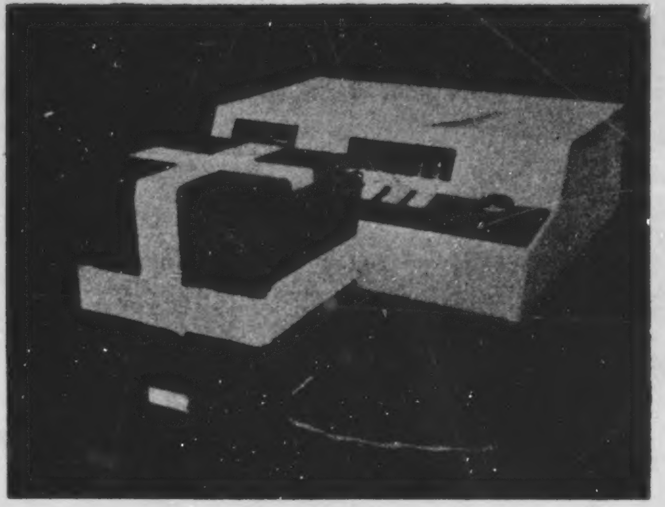


FIGURE 3-1

Q1 - Does background radiation vary from one part of the building to another?

Q2 - Does background radiation appear to come from radioactive samples stored in the room?

Q3 - Did the lead shields affect the count?

Q4 - Can you suggest some possible sources of background radiation?

PART II

As a further check on background radiation, place charged dosimeters in various locations for one week. Each group should select a different type of location. Some suggested places are:

1. Carried with you
2. In your home
3. In your locker
4. In a basement
5. Next to a brick and/or stone wall
6. Enclosed in a heavy lead shield

7. Next to a "glow in the dark" clock
8. If you know a pilot or someone who flies to high altitude cities such as Denver, ask if he would carry a dosimeter with him on such a trip.
9. Try to find a dentist, doctor, or X-Ray technician who will "X-Ray" a dosimeter for a few seconds.
10. Next to a color TV

After a week read all the dosimeters. Pool your data so each group knows all the dosimeter readings.

Q5 - Did any of the dosimeters show a change which could be read?

Q6 - Was any location free of all radiation? (If you can't read any change on the dosimeter, does that mean no radiation was present?)

Q7 - If your dosimeters did show a change, which location showed the highest amount of radiation? The lowest?

Refer back to the experiment where you determined the radiation dose in the Gammator chamber to help you answer Q8 and Q9.

Q8 - How many roentgens of exposure occur each second in the chamber?

Q9 - Refer to the readings on your dosimeters in this experiment. How long an exposure to your environment would it take to equal the radiation exposure of 1 second in the Gammator?

PART III

It is known that some background radiation comes from cosmic rays which originate outside our atmosphere. Are there also radiation sources in our atmosphere? In this part of the experiment we will collect dust from our atmosphere and determine whether or not it is radioactive. It may be necessary to work together as a class on this part.

With the G-M tube 1 cm away, take a radiation count (at least 2 minutes) on a piece of clean filter paper. Place a piece of screen wire over the intake of a tank type vacuum cleaner. Position the piece of filter paper over the screen so that air will be drawn through it. As an alternate procedure, a high volume air sampler can be used. It has the advantage of a larger filter which can be cut up to provide samples for several groups.

Place the vacuum cleaner (or air sampler) on the school roof or grounds. Operate for about 4 hours. Then place the dirty filter paper, as before, 1 cm from the G-M tube. Take a count.

Q10 - Did any radioactive material (fallout) collect on the filter paper?

Q11 - What can you suggest as possible sources of radiation in our atmosphere?

Q12 - Considering all parts of this experiment, do you think you can completely escape all radiation?

Q13 - Is background radiation apparently harmful?

EXPERIMENT 3-3

IRRADIATION OF FLOUR BEETLES

INTRODUCTION:

We learned in Experiment 3-1 that irradiation does not produce radioactivity. Might it produce other effects on living things? Can radiation be harmful to living organisms? In this experiment we will irradiate small insects known as flour beetles.

MATERIALS NEEDED:

Hand lens
Camel hair brush
Kitchen sieve
Flour beetles in flour culture medium
Paper towel
Gammator

PROCEDURE & INTERPRETATIONS:

Your teacher will give each group a flour beetle culture. Each vial will contain several live beetles. Every even numbered group place your vial in the Gammator for 24 hours. Every odd numbered group leave your vial out of the Gammator. These will serve as controls.

After 24 hours, determine the number of living and nonliving beetles by following this procedure:

Place two pieces of paper towel or clean paper (typing paper) before you. Hold a clean sieve above one of the pieces of paper. Empty the contents of your vial into the sieve and gently shake up and down until all the flour is on the paper and the beetles remain in the sieve. Place the beetles on the clean piece of paper. While observing under a hand lens, stimulate each beetle by touching with a camel hair brush and note the slightest response. If no response, the beetle may be considered dead.

Pool your data with other groups so that all class members have a record of the total number of live beetles and the total number of dead beetles in the irradiated samples and in the non-irradiated samples.

Q1 - Was there a significant difference in the percent of living and dead beetles in the two samples?

Q2 - Can radiation kill flour beetles?

EXPERIMENT 3-4

EFFECTS OF VARYING RADIATION DOSE ON FLOUR BEETLES

INTRODUCTION:

Will the amount of radiation dose necessary to kill some organisms in a species kill all the organisms of that species? Is there a time span during which harmful effects are seen?

These are some of the questions we hope to answer in this experiment. Of course, many other variables might be explored if time permitted. Among the most obvious are these: Would old animals (nearing the end of their natural life span) be more affected by radiation? Would animals on a diet of poor nutrition be more affected than animals on a nutritional diet? The obvious answer is not always the right answer. That, perhaps, is one of the reasons why scientists keep on experimenting.

MATERIALS NEEDED:

Hand lens
Camel hair brush
Kitchen sieve
Flour beetles in flour culture medium
Paper towel
Gammator

PROCEDURE & INTERPRETATIONS:

Your teacher will give each group a flour beetle culture. Each vial culture will contain 10 beetles of approximately the same age (within 5 days) and the same sex. (This is so the beetles will not reproduce during the time span of the experiment.) Groups will be assigned a radiation dose for their culture as follows:

	IRRADIATION TIME (Minutes)
GROUP 1	0
GROUP 2	4
GROUP 3	8
GROUP 4	12
GROUP 5	16
GROUP 6	20
GROUP 7	24
GROUP 8	28

Additional groups select any time you desire

Irradiate your culture in the Gammator for the assigned time. Remove the culture vial, label properly, and store in the place designated by your instructor.

Q1 - What dose, in roentgens, did your beetles receive while in the Gammator? (Refer to your answer to Q4, Experiment 7.)

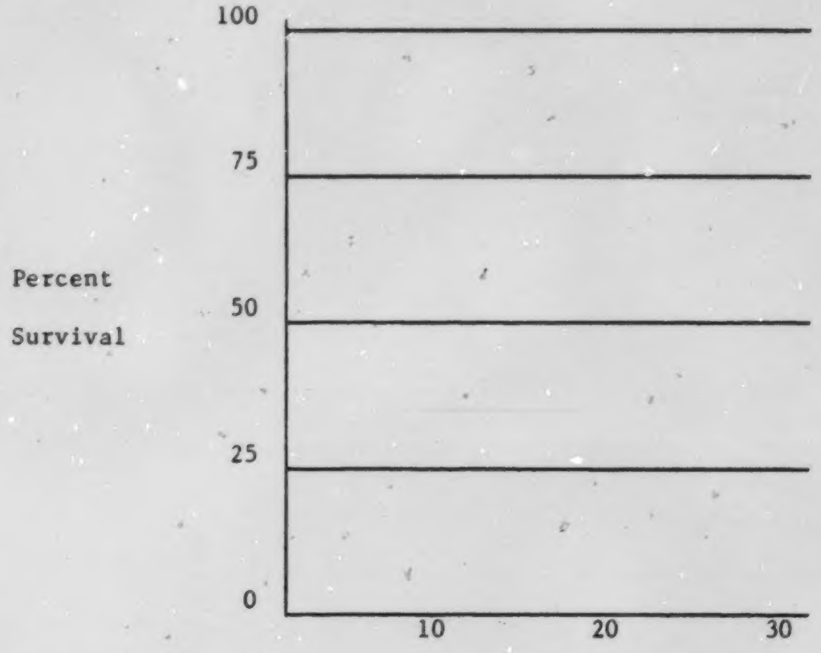
"Pool" your answers to Q1 with other groups and then add columns of data in your lab notebook, listing exposure time and the corresponding dose. Follow the procedure described below on the 7th, 14th, 21st, and 28th day following irradiation.

Place two pieces of paper towel or clean paper (typing paper) before you. Hold a clean sieve above one of the pieces of paper. Empty the contents of your vial into the sieve and gently shake up and down until all the flour is on the paper and the beetles remain in the sieve. Place the beetles on the clean piece of paper. While observing under a hand lens, stimulate each beetle by touching with the camel hair brush and note the slightest response. If no response, the beetle may be considered dead.

After careful observation, replace the living beetles in the vial and replace flour nutrient. Cap as before and replace the vial in the incubator. Discard the dead beetles and record your results.

At the end of 28 days (four observations) make a graph of your results. Exchange information with the other groups to complete your graph. If you plot several lines on the same graph, devise some system for distinguishing the different lines.

Graph as follows:



Days after irradiation

FIGURE 3-2

Q2 - Do some beetles survive each radiation dose?

Q3 - Is there any radiation dose (in roentgens) which seems lethal (deadly) to about 50 percent of the population? This would be called LD-50 (lethal dose-50 percent of the population). This could be more accurately written LD 50 - 28 days.

Q4 - Determine the number of days necessary for an LD 50 for each line on your graph.

EXPERIMENT 3-5

RADIATION EFFECTS ON SEEDS

INTRODUCTION:

We have seen from the last two experiments that radiation affects animal life. Does it affect plants also?

MATERIALS NEEDED:

Gammator
Metric rule (10 cm)
Two kinds of seeds (labeled A and B)
Container for seeds during irradiation
Two seed growing trays
Germinating soil
Scissors

PROCEDURE & INTERPRETATIONS:

Prepare the seeds by discarding extra large, small, broken, discolored or misshapen seeds. One partner count out 100 uniform "A" seeds while the other partner counts out 100 uniform "B" seeds. Place the seeds in appropriate containers in preparation for irradiation. Your teacher will assign each group a radiation dose for the seeds. The dose will be given in kiloroentgens (kr). A kiloroentgen is 1,000 roentgens. Calculate the time your seeds must remain in the Gammator to receive the kr dose assigned. (Refer to your answer to Q4, Experiment 7.) Mark your exposure time on the seed container. Some of the samples receiving large exposures will have to be removed later in the day.

The growing trays are ready for the seeds. They will be labeled as shown in FIGURE 3-3.

Seed A
0 2.5 5 10 20 40 80 160

TRAY LABEL SHOWING DOSES IN kr

FIGURE 3-3

Make a shallow row about ¼ inch deep to extend the long way of the tray. Be sure to match the row with the kr label on the end of the tray. Sow your seeds in the proper row.

Keep the trays at room temperature and moist, but not soggy.

PART I: GERMINATION RATE

Seven to ten days after planting the seeds, some seedlings should be about 10 cm in height.

At this time count your seedlings with care.

Q1 - How many seeds did you plant?

Q2 - If 85 of these grew, what would be the percent of survival?

Make a data table showing the kr dose and the percent of germination for both types of seeds.

Example:

DOSE	EXPOSURE TIME	PERCENT GERMINATION	
kr	Min.	Seed A	Seed B
0			
2.5			
5			
10			
20			
40			
80			
160			

FIGURE 3-4

Exchange information with the other groups so that you can complete the data table.

Q 3 - Which of seeds A had the highest percent of germination? Which of seeds B?

Q4 - Which of seeds A had the lowest percent of germination; Which of seeds B?

Q5 - Can irradiation affect seed germination?

Q6 - If so, which seeds, A or B, were most affected?

PART II: AVERAGE LENGTH OF SEEDLINGS

Harvest your row by carefully cutting the first 50 plants at ground level. Use scissors for harvesting the plants. Place the harvested plants on a white paper, and measure each one to the nearest millimeter. One of each team can measure while the other records. After measuring all 50 plants, find a total of all measurements and divide by 50. This will give you the average length.

Make a data table similar to FIGURE 3-5

DOSE	AVERAGE LENTH (mm)	
kr	Plant A	Plant B
0		
2.5		
5		
10		
20		
40		
80		
160		

FIGURE 3-5

Exchange information with other groups to complete the data table.

Q 7 - Which of plants A had the longest average? Which of B?

Q8 - Which of plants A had the shortest average? Which of B?

Q9 - Can irradiation of seeds affect growth of plants?

Q10 - If so, was A or B most affected?

* * * * * * * * * * * *

We have seen that radiation, in sufficient quantity, may result in death. There are, however, other more subtle dangers of radiation exposure. The following experiment will illustrate the two basic non-lethal effects of radiation.

EXPERIMENT 3-6

RADIATION AND LIFE

INTRODUCTION:

During the past five experiments we have investigated some of the effects of radiation on non-living and living materials. In this experiment we will try to draw some conclusions based on the results of these labs.

MATERIALS NEEDED:

Results of Experiments 3-1 through 3-5
Paper and pencil

PROCEDURE & INTERPRETATIONS:

Suppose that a group of 20 mice received a 400 roentgen radiation dose. Within 3 weeks 5 of the mice died. (We will assume that radiation was the cause of death.)

Q1 - Is it possible to tell, in advance, how much radiation it would take to kill a given mouse?

Q2 - How could you express the expected lethal effects of another 400 roentgen radiation dose on a similar group of mice?

Q3 - Why do you think that a radiation dose which kills some mice, doesn't kill them all?

The remaining 15 mice survived. They were observed and compared to another group of the same age which had not been irradiated. In time, the fur of the irradiated mice began to turn grey, whereas that of the control group (non-radiated) remained dark.

Q4 - What evidence have you that the change in fur color resulted from the radiation exposure?

The biological effects of radiation can be placed in two categories:

A. "Somatic" effects which result in changes in the individual but have no effect on future generations, and

B. "Genetic" effects which result from damage of certain cells in the reproductive organs. Changes in certain characteristics of future generations can be the result. (If there is a sudden change in the hereditary pattern we say a mutation has occurred.) An individual showing a mutation is called a mutant.

Q5 - Was the change in fur color of the 15 mice a genetic or a somatic effect?

Q6 - What experiments have you done in which somatic damage occurred?

Q7 - Have you done any experiments in which genetic changes occurred?

Q8 - Suppose that some of the 15 surviving mice reproduced. Would you expect their offspring to have grey fur? Explain.

Q9 - All of the original mice had brown eyes. The offspring of a pair of the irradiated mice had pink eyes. Was this change of eye color a genetic or somatic effect?

A genetic change means that there has been an alteration in the genetic makeup of a reproductive cell. It may have been caused by radiation. Regardless of the cause, the new pattern will continue to reproduce itself.

Q10 - Suppose two of the pink-eyed mice were mated. Would you expect some or all of their offspring to have pink eyes?

Q11 - Another group of mice were given a dose of 50 roentgens a week for 10 weeks. All of these mice continued to survive. How could you explain their survival even though they received a larger total dose than the original group?

Q12 - Although the probability of occurrence is extremely low, a single radiation particle or ray, in the right spot, can produce a mutation. Would spreading a dose of radiation over a long period of time reduce the chance of genetic damage?

Q13 - Would spreading a dose of radiation over a long period of time reduce the chance of permanent somatic damage?

Q14 - Would you expect the lethal dose for man to be the same as the lethal dose for mice? (Remember the results of the seed irradiation experiment.)

Q15 - If a person is exposed to a relatively large dose of radiation and feels no ill effects, can he be sure that no genetic damage has occurred? Explain.

Q16 - In terms of genetic damage, which part of the body should be most protected from radiation exposure?

An important question remains: How much radiation exposure is too much? We will attempt to answer this question later.

* * * * * * * * * * * *

During the next two experiments we will briefly depart from our study of the effects of radiation. Soon you will be working with radioactive materials in the form of liquids. Since liquids can be spilled, spread around, and absorbed, their use requires much more care than when working with solid sources. The following lab will acquaint you with some of the procedures to be followed when working with radioactive liquids.

EXPERIMENT 3-7

SAFE HANDLING OF RADIOACTIVE LIQUIDS

INTRODUCTION:

How are radioactive liquids (radioisotopes) safely handled and disposed of?

The techniques used in this lab should be used whenever you are working with liquid radioisotopes.

In this lab you will be asked to measure, dilute, transfer, dry and take counts on radioactive samples. Pay particular attention to the techniques used and the health safety practices to be followed. Throughout all labs, immediately report all spills of radioactive materials to your instructor.

MATERIALS NEEDED:

1 Safety tray
1 Liner for safety tray
Disposable plastic gloves
Talcum powder
Survey meter
1 ml liquid radioisotope
Radiation warning labels
1 Small test tube (about 75 mm)
Test tube rack
1 Syringe pipette
1 Beaker (for contaminated glassware)
Wiping tissues
1 Planchet
1 Dropper pipette
Forceps
Heat lamp
Detergent
G-M tube
Scaler
Radioactive waste can
Distilled water

PROCEDURE & INTERPRETATIONS:

A. Line a safety tray with a waterproof liner. All handling of the radioisotopes should be done on this tray.

B. Obtain a pair of disposable plastic gloves. These should be worn whenever handling the radioisotopes. If difficulty is experienced in putting on gloves, dust hands with talcum powder.

C. Have a survey meter nearby so one of your work team can monitor the work area periodically throughout the experiment.

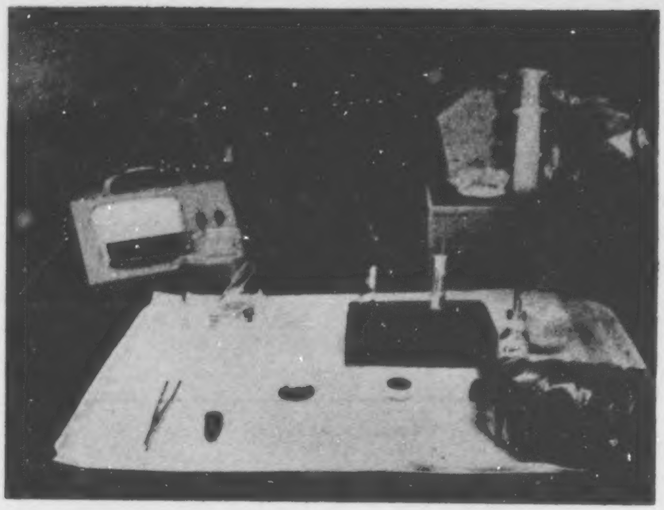


FIGURE 3-6

D. Books, pencils, and all other materials not directly related to the experiment should be removed from the work area.

E. Obtain a bottle containing a radioisotope from your instructor. (Be sure you are wearing plastic gloves.)

F. Place a radiation warning label on a test tube and place it in a test tube rack on your safety tray.

G. Using a syringe-type pipette, practice withdrawing and expelling distilled water until you can use it accurately. Then withdraw .1 ml of the radioisotope from the bottle and transfer it to the test tube. CAUTION: Never draw radioactive liquids into a pipette by mouth. Add 2 or 3 pipettes full of distilled water to the test tube to rinse the pipette. Place the pipette in a beaker or other container for contaminated glassware to be washed later. This beaker should be labeled with a radiation warning label.

H. Recap the radioisotope. Wipe the outside of the bottle with a tissue and monitor the tissue for contamination. If contaminated, dispose of the tissue in the special container for radioactive wastes and leave the bottle on the safety tray to be cleaned later. If it is not contaminated, return the bottle to its storage place.

I. Add water to the test tube until the original sample is diluted to 1.0 ml.

J. Using a dropper pipette, transfer 5 drops of the radioactive solution to a clean planchet. Place the dropper in the beaker for contaminated glassware.

K. Using forceps or tweezers, place the planchet under a heat lamp so it can dry slowly. Don't heat so rapidly that it will spatter. Monitor the forceps and if contaminated, rinse and monitor. Repeat until they are decontaminated.

L. While your sample is drying, clean up your work area. Pour the radioisotopes remaining in your test tube into the designated container. Place the test tube in the beaker for contaminated glassware.

M. Wash all contaminated glassware with hot water and detergent. (Use the designated "hot" sink.)

N. Rinse and dry the glassware. Monitor the glassware and the paper toweling used for drying. Repeat the process until they are decontaminated.

O. Monitor your work area and scrub any contaminated areas until they are "clean."

P. Put the safety tray liner in the radioactive waste container. Handling by the cuffs only, remove your plastic gloves and place them in the radioactive waste container.

Q. Wash your hands with soap and water. Monitor your hands for contamination. If they are contaminated, wash with soap and water again and monitor. Repeat until they are free of contamination.

R. When your hands and work area are free of contamination, use a G-M tube and scaler to make a count of the activity of your prepared and dried sample. Take at least a 3-minute count and correct for background radiation.

S. Dispose of your planchet in the radioactive waste container.

T. Again, monitor your hands and clothing before leaving the lab.

* * * * * * * * * * *

In the experiment we have just completed, we learned some procedures to follow for the safe handling of radioisotopes. But what if an accident does occur? And how should you dispose radioactive materials? The next experiment will help us answer these questions.

EXPERIMENT 3-8

CONTAMINATION AND DISPOSAL

INTRODUCTION:

What are some of the problems involved in radioactive contamination and waste disposal? Do some radioactive materials present more of a contamination and waste disposal problem than others? In this experiment you will answer some questions by doing lab work and others by doing library research.

MATERIALS NEEDED:

Small samples of glass, wood, metal (shiny), metal (rusty), painted wood, rubber, brick or concrete and cloth
End window G-M tube
Scaler
*Minigenerators™: Strontium 90/Yttrium 90
Cesium 137/Barium 137 m
Heat lamp
Small beaker, test tube, or vial
Safety tray and liner
Plastic gloves
Eye dropper
Soap or detergent
2 Wooden blocks
Radiation warning labels
Resource materials on radioactive waste disposal
Ring stand
Buret clamp

*The term Minigenerator is a trade mark of Union Carbide Corporation.

PROCEDURE & INTERPRETATIONS:

PART I

Place one of the samples listed at the top of the "Materials Needed" list on your safety tray and liner. Each group should select a different sample and "Pool" your results. Slowly elute 2 drops of Yttrium-90 solution from the minigenerator onto the center of your material sample. (If you are using the piece of cloth, place it in a shallow dish so that the radioisotope doesn't soak into the tray liner.)

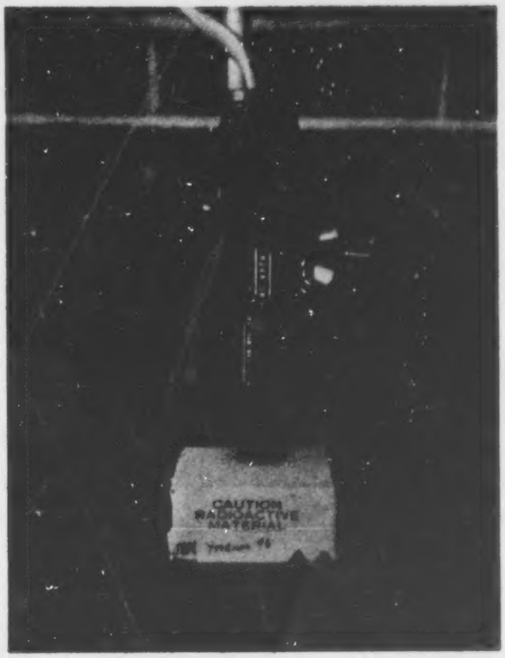


FIGURE 3-7

Dry the sample by placing a heat lamp over the safety tray. While the samples are drying, set up the end window G-M tube so a count can be taken on each sample without changing the tube position throughout the experiment. See FIGURE 3-7. After the samples are dry, record the background count and then take a 1 or 2 minute count on each sample. Let the samples cool for a short time before taking a count, otherwise the heat may shatter the window on the G-M tube.

Now, following as uniform a procedure as possible, (Be sure you are wearing plastic gloves) rinse each sample in clear water for 30 seconds. Dispose of the rinse water in the "hot" sink. Carefully place the wet sample under the G-M tube and take another count. (If time permits, dry your sample under a heat lamp before taking the count.)

Now scrub the samples with hot water and soap for a full minute each. Rinse and take another count.

"Pool" your data with the other lab groups.

Q1 - Which (if any) samples remained most contaminated after the initial rinsing?

Q2 - Which (if any) samples remained most contaminated after scrubbing with soap and water?

Q3 - What type of material would you recommend for the counter tops and walls in areas where radioactive liquids are to be used?

PART II

Do some radioactive materials present a more difficult disposal problem than others? "Contaminate" two identical blocks of wood as follows:

On Block #1 place 5 drops of Yttrium-90 solution.

On Block #2 place 5 drops of Barium-137m solution.

Dry the blocks under a heat lamp and take a radiation count on each. Correct for background radiation. Mark with a pencil the spot you are counting on the block. Measure and record the distance between your tube and block. Mark the blocks with radiation warning labels and store in a safe place for 24 hours.

After 24 hours take another count on each block. Be sure to center your tube on the penciled mark and get the same distance you had before. Correct for background radiation.

Q4 - Which would present a more serious problem, spillage of Yttrium-90 or Barium -137M? Why?

PART III

The remainder of this experiment is to be done in the library, or using the reference materials provided by your instructor. Research the available literature and try to answer the following questions:

Q5 - What are the most common methods now being used to dispose of radioactive wastes?

Q6 - Are any of these methods entirely satisfactory? Explain.

Q7 - What are some other possible methods of disposal that might be used in the future?

Q8 - Suppose you were to drop a test tube containing a fairly large amount of a liquid radioisotope. It hits the work counter and breaks. The liquid spatters on the work counter, the floor, your shoes, your arm, your sleeve and your books. Describe the step by step procedure you would follow after the accident. Assume your instructor is unavailable to assist you.

EXPERIMENT 3-9

INTAKE OF RADIOACTIVE PHOSPHORUS BY FISH

INTRODUCTION:

Can radioactive materials from the environment enter the respiratory or digestive tract of an animal and be transported to and incorporated into other parts of its body? If a fish is placed in water containing radioactive phosphorus, will any of this radioactive phosphorus be taken in and incorporated into parts of its body?

MATERIAL NEEDED:

2 Small smooth walled aquaria (gallon jars will do) with aeration systems
Phosphorus-32
2 Goldfish
Dip net
4 Beakers
Anesthetizing solution
Plastic wrap
Hotplate or bunsen burner
Dissecting kit
Autoradiograph materials: film packet, developer

81

Radiation warning labels
Safety tray and liner
Disposable plastic gloves

PROCEDURE & INTERPRETATIONS:

Your teacher will furnish two containers filled with water. Each group will place a well-fed, healthy goldfish in each container. The teacher will now add 10 μc of phosphorus-32 to one of the containers. After two to five days, use a dip net to remove a goldfish from the "hot" (radioactive) container. Remember to wear plastic gloves. Rinse in three or four clear water baths to remove any external phosphorus solution. The fish can be transferred from bath to bath using a dip net. From this point on, one lab partner will work with this fish and the other will work with a fish from the other (non-radiactive) tank. The remaining directions should be followed on each fish. Place each fish in the anesthetizing solution provided by your instructor. After the fish is anesthetized, replace the solution with fresh water. Heat the water and the fish to the boiling point. Remove the fish. Dissect into three parts: Internal organs, muscle, and skeleton. Be sure to use a safety tray and wear plastic gloves while working with the fish that has been in the radioactive phosphorus solution. Prepare an autoradiograph of your fish parts. Keep the internal organs, the muscle, and the skeleton in separate positions. See FIGURE 3-8. If room permits both you and your lab partner should put your fish parts on the same film packet.

FIGURE 3-8

Cover the parts with a piece of plastic wrap and press with a heavy object such as a book. This should insure that all parts are pressed tightly against the film packet.

After 24 hours, develop your autoradiograph. Refer to the developing procedure in Experiment 2-1.

Q1 - Are either of the fish radioactive? Explain.

Q2 - If either of the fish were radioactive, which part(s) were the most radioactive?

Q3 - Explain why one part might contain more radioactivity than another?

Q4 - Why should radioactive materials taken into the body be more dangerous than periodic exposure to external radiation?

Calcium and strontium have similar chemical properties. Milk contains a considerable amount of calcium. The human body uses calcium in building bone tissue.

Q5 - Assume that some milk cows feed upon grass which is contaminated with radioactive strontium fallout. Explain how this radioactive strontium could end up in your bones.

EXPERIMENT 3-10

INTERNAL AND EXTERNAL RADIATION

INTRODUCTION:

Is one type of radiation more dangerous than another? How do the dangers of radiation sources inside and outside the body compare? Before attempting to answer these questions, review the results of Experiment 2-9 in which you studied the properties of alpha, beta, and gamma radiation.

MATERIALS NEEDED:

Results of Experiment 2-9
Paper and pencil

83

PROCEDURE & INTERPRETATIONS:

Q1 - Which type of radiation is most penetrating?

Q2 - Which type of radiation is least penetrating?

Let's consider some of the reasons for this difference. We already know that radiation causes ionization. To produce an ion pair requires energy. Alpha and beta particles can, as a result of their electric charge, cause electrons to be knocked free from atoms as they pass nearby. The electron plus the remainder of the atom form an ion pair. Many ion pairs form from the passage of one alpha or one beta particle.

Now let's compare the ionizing effects of alpha and beta particles.

Q3 - Which particle has the greater charge, alpha or beta?

Q4 - Which particle is heavier, alpha or beta?

Q5 - If they have the same amount of energy, which is moving faster, alpha or beta?

If you had trouble answering any of the above questions, recall that a beta particle consists of 1 electron (with one negative charge) and an alpha particle consists of 2 protons (with 1 positive charge each) and 2 neutrons (with no charge). In comparing speeds think about a freight train and a bullet. Wouldn't the small bullet have to be traveling much faster to have an energy equal to that of the much heavier freight train?

Now think about an alpha particle and a beta particle speeding past an atom. The alpha particle with its 2 charges goes past much slower than the beta particle with its single charge.

Q6 - Which would exert a greater force on the electrons of the atom?

The alpha particle really has 2 advantages, it pulls with twice the charge and for a longer time.

Q7 - Based on your answer to number 6, which particle would produce the most ion pairs in .1 cm of travel?

Q8 - Now think about the ability of the 2 particles to penetrate. If both particles have the same amount of energy and if the formation of each ion pair requires a specific amount of energy, which particle could travel further before it runs out of energy? (Remember your answer to Q7.)

Q9 - Based upon these answers, which particle should have the greatest range?

Q10 - Does this agree with your observations from Experiment 2-1?

Now let's consider gamma radiation. It travels at the speed of light which is faster than any particle can travel. Even though it is not a particle, it can produce ionization if it hits an electron. Recall that an alpha or beta particle must only pass nearby.

Q11 - Compared with alpha and beta radiation, would you expect it to travel farther or not as far to expend its energy?

Now for the purpose of illustration, assume that an alpha particle, a beta particle, and a gamma ray are all traveling the same direction. Furthermore, assume each has enough energy to form 5 ion pairs. In FIGURE 3-9, each X represents the formation of an ion pair.

Q12 - Which arrow represents the path of the alpha particle, which the beta particle and which the gamma ray?

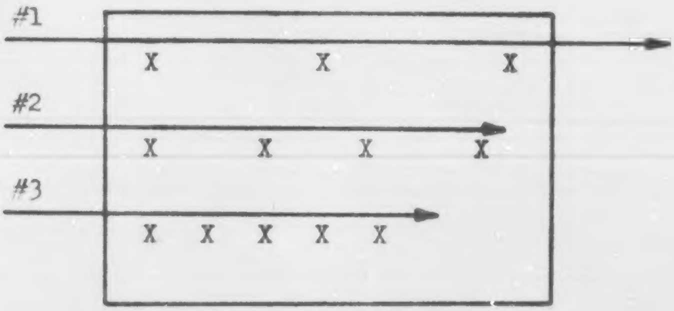


FIGURE 3-9

You have seen from earlier experiments the penetrating ability of the various radiations. In terms of penetration into the body, gamma rays can penetrate many centimeters of flesh. In fact if you held your arm in the path of gamma radiation, perhaps half of it would pass completely through. Beta particles can penetrate no more than a few millimeters of flesh and alpha particles cannot penetrate the outer layers of dead skin to reach living tissue. Does this mean that alpha radiation presents no hazard? Before we answer let's consider two more ideas.

First, the harmful biological effects of radiation result from ionization within the cell. The presence of ions may interfere with the function of the cell or the radiation may do direct damage to vital molecules within the cell. Whatever the mechanism, sufficient ionization can be fatal to the cell.

Second, radiation can be either external or internal. That is, it may come from outside or inside the body. Let's consider these types separately.

EXTERNAL RADIATION

Q13 - Which type of external radiation can cause skin burns but cannot damage internal organs?

Q14 - Which type of external radiation will not damage any living tissue in your body?

Q15 - Which type of external radiation could affect your internal organs?

Q16 - Sometimes internal tumors are treated by irradiating them with beams of external radiation. Which type of radiation must be used?

Q17 - Is exposure of the skin to external alpha radiation dangerous?

Q18 - Which type of external radiation presents the greatest hazard?

It should be noted that severe burns over enough of the body can be fatal. Therefore, external beta radiation in massive whole body doses can be dangerous even though it doesn't penetrate to the internal organs.

INTERNAL RADIATION

Radiation, particularly alpha radiation, presents a much different problem internally than externally. Sources of radiation can be taken into the body by breathing in airborne contamination, by eating contaminated food, by licking your finger while working with radioisotopes, etc. If this happens, the radioactive material can end up next to living cells or, through biological processes, be taken into living cells.

Now refer back to FIGURE 3-9 as you answer the following questions:

Q19 - Which radiation produces its ionization within the shortest distance?

Q20 - Remember that the more ionizations that occur within a cell, the more likely the cell is to die. If sources of alpha, beta, and gamma radiation are in a cell, which is most likely to kill it?

Q21 - Is internal alpha radiation dangerous?

Again, as we did just prior to FIGURE 3-9, assume that we have an alpha particle, a beta particle, and a gamma ray, each with the same energy. They all originate inside the body.

Q22 - Which radiation might escape the body without expending all of its energy?

Q23 - How would the number of ion pairs formed by the alpha and the beta compare? (Assume neither radiation escapes the body.)

Q24 - Which radiation would produce the greatest concentration of ion pairs?

Now let's summarize what we have discovered so far. Gamma radiation is the most penetrating and most hazardous of external radiations. Alpha radiation is the least penetrating but produces a high ion concentration. It is the most hazardous if it occurs internally. Beta radiation occupies an intermediate position in both respects.

When working with alpha sources in the lab, work with care. Remember that external sources may, through contamination, become internal.

One final factor should be noted. A concentration of radioactive materials can occur because some isotopes have a chemical affinity to a particular tissue in the body. These are sometimes called "tissue seekers." Example: Phosphorus is a bone seeker in fish. Consider three research animals. Each is given a radioisotope. The isotopes are soluble and ingested with food. Assume that each isotope possesses the same level of activity, and is given to the research animals in identical quantities.

Animal A is given isotope X.

Animal B is given isotope Y.

Animal C is given isotope Z.

Isotope X is a red blood cell seeker and a gamma source.

Isotope Y is a bone seeker and a beta source.

Isotope Z is a thyroid gland seeker and an alpha source.

Assume one could excise 1 cm^3 of tissue from various parts of each animal and examine it for radiation effect. The following is excised from each animal.

One cm^3 muscle, left leg.

One cm^3 bone, right leg.

One cm^3 thyroid gland.

Q25 - Which animal would show the largest radiation concentration in each of the above tissue samples?

Q26 - In each of the above cases, comment on the possible effect to the surrounding tissues.

Q27 - From the information you have learned about tissue seeking isotopes, can you suggest examples of how they might be used in medical science?

* * * * * * * * * * *

Now that we have seen some of the effects of radiation exposure, let's consider the sources of radiation and try to put the hazards into their proper perspective.

Man has lived, since his beginning, in an environment of natural radiation. We are all in the same boat, so let's relax. The stone, concrete or brick in the construction of the building in which we now sit is giving off radiation. Often the water we drink is radioactive. Shall we escape by going deep in a mine or cave? No good. The rocks and minerals around us contain radioactive materials. Shall we get away by going up in a plane? What the heck, radiation is doubling for every mile we go up. Cosmic radiation bathes the planet.

Man also adds to our radiation background. The air we breathe contains radioactive fallout from various industrial processes. Some debris from nuclear explosions may remain airborne for at least 5 years. Medical uses, such as X-rays, add to our radiation dose. All of these sources combined will give us a maximum whole body dose of about .15 r per year. Is this dose significant? Certainly not as far as somatic effects are concerned. FIGURE 3-10 shows the doses necessary to produce observable effects in man:

EFFECTS OF WHOLE BODY PENETRATING RADIATION

DOSE	PROBABLE EFFECT
0-25r	No obvious injury
25-50r	Possible blood changes, but no serious injury
100-200r	Injury, possible disability
200-400r	Injury and certain disability, death possible
400-600r	Fatal to 50% (LD-50)
600 or more	Fatal

FIGURE 3-10

When large doses are absorbed, what are the injurious effects? Doses of 200 r will usually prevent blood cells from being produced by the tissue which forms them. It may also prevent the replacement of cells lining the intestinal tract. Other effects involve the central nervous system, the thyroid, the lungs, and the eyes. Radiation may destroy the body's ability to produce antibodies making the victim easy prey to disease and infection. A 200 r dose may also result in malformed embryos and cancer or leukemia.

The above somatic effects require single doses about 1,000 times the normal background radiation for an entire year. Because of this, biologists maintain that the most harm done by radiation is genetic in nature. It can cause mutations and these mutations, once caused, will probably be with mankind to the end of time.

There is no threshold for genetic effects. Any amount of radiation can cause mutation, although the higher the dose, the greater the chance of a mutation occurring.

The black sands of Guarapari in Espirito Santo, Brazil, produce a natural radiation which is about 300 times greater than our normal background and is often larger than our government agencies will allow a radiation worker. Yet research to detect a difference in the mutation rate in this area is inconclusive at this writing.

How should you live your life? When Bill yells, "Come on, I'll give you a ride to school," will your response be, "No thanks, 55,000 will lose their lives in traffic accidents this year." When it is hot and you want a swim in the lake or pool, will you stay home because 6,000 will drown this year? When your mother calls, "Come to dinner," will you decline because 3,100 will suffocate due to food obstruction?

No, you will ride in a car, or drive a car, but if you are prudent, you will avoid driving while drunk or going 120 mph. That is the attitude we should have toward radiation. Be aware of the effects of time on radiation exposure. Be aware of the effects of distance. Be knowledgeable about shielding. (You will learn more about all these factors in the next chapter.) Keep in mind your senses do not respond to radiation, so be sure it is safe before you handle it.

Above all, do what you can to change the attitude of the alarmist. You have learned that external radiation cannot make something else radioactive. Other people may not understand this.

You live in a nuclear age. Radiation effects your life daily; in the food you eat, the clothes you wear, the cars you drive, the tools you work with, the electricity you read this by, the heat that warms you in winter, and the medical services that keep you well. Accept the benefits of radiation, just as you respect the harm it can do.

CHAPTER IV

PROTECTION FROM RADIATION

If radiation can have harmful effects on living organisms, how can we protect ourselves from it? What factors affect the radiation dose which we receive? What sources of radiation are we normally exposed to? The experiments in this chapter should help you answer these and similar questions. First we will investigate the effect of time on radioactivity.

In the following experiments, we will be using a new type of graph paper called semi-log paper. Before beginning the next experiment, complete the assignment in Appendix E.

EXPERIMENT 4-1

RADIOACTIVITY AND TIME #1

INTRODUCTION:

If we were exposed to a radioactive source for two hours, would we receive twice the radiation dose that we would receive in one hour? It would seem so unless the level of radiation changes during the two hours. Does radioactivity change with time or does it go on forever?

In this experiment, we will study the effects of time on radioactivity.

MATERIALS NEEDED:

Minigenerator Cs137/Ba137m
Planchet
G-M tube
Ring stand and buret clamp
Scaler (or count rate meter)
Safety tray and liner
Plastic gloves
Timer
Regular graph paper
Semi-log graph paper

PROCEDURE & INTERPRETATIONS:

Clamp the G-M tube onto a ring stand with a buret clamp. Its position should be about 2 cm above the planchet.

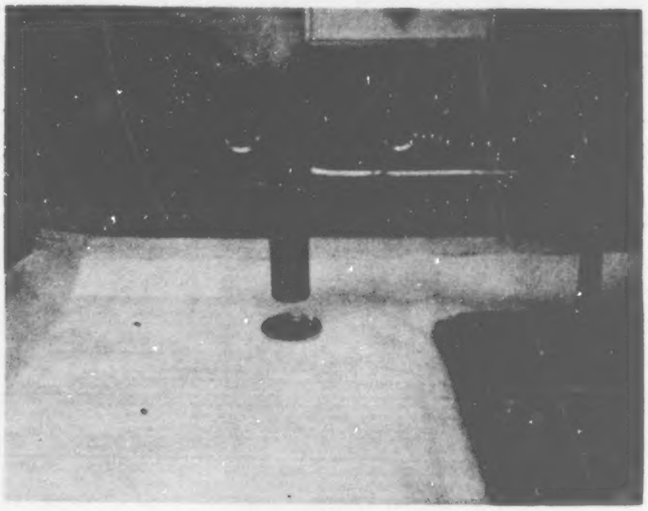


FIGURE 4-1

Turn on the scaler and allow it to warm up. Measure and record the background count with no source near the G-M tube.

Obtain a minigenerator from your instructor. Elute 3 drops from the minigenerator into a planchet. (Use safety tray and gloves.) Place the G-M tube over the planchet. See FIGURE 4-1. The position of the G-M tube and planchet should not be changed throughout the rest of the experiment.

93

TOTAL ELAPSED TIME (Min)	COUNTING INTERVALS (Min)	TIME OF COUNT (INTERVAL MID-POINT) (Min)	GROSS COUNT (c/m)	CORRECTED COUNT (c/m)
0	0-1	.5		
1				
2	2-3	2.5		
3				
4	4-5	4.5		
5				
.	.	.		
.	.	.		
.	.	.		

Extend your data table to cover a total elapsed time of about 15 min.

FIGURE 4-2

In order to obtain counts at known times you should take counts every other minute. During the alternate minutes you should record your data and reset your scaler. Example: You count from time 0 to 1 minute. Between minutes 1 and 2 you reset and record and then count from minute 2 to minute 3. You would like to know the average count rate for each interval. Since the average should occur near the middle of the interval that is the time recorded. Example: When you record the time for the count between minute 2 and minute 3, it is recorded as 2.5 minutes. See FIGURE 4-2.

(NOTE: If a count rate meter is available, the procedure is simpler. In that case the count rate is simply read from the meter dial at the end of each minute.)

Q1 - Do your recorded values show a significant change during the 15 minutes?

Q2 - If there is a change, does it appear to be the result of a random fluctuation or does it appear to vary according to a pattern?

Perhaps a graph would help you determine if a pattern exists.

Using regular graph paper, plot a graph showing corrected counts/minute on the vertical axis and time of count on the horizontal axis.

Q3 - Did the count rate change at a constant rate?

Q4 - Does there appear to be any predictable pattern in the variation?

Now plot the same data using semi-log graph paper. Again plot corrected counts/minute on the vertical axis and time on the horizontal axis.

Q5 - What is the general shape of the graph?

Q6 - Using either or both graphs, determine the time required for the counts/minute to drop to half its original value.

Q7 - What additional time is required for the counts/minute to again be cut in half? ($\frac{1}{4}$ the original value)

Q8 - Which graph is easiest to use in determining these values?

Q9 - Without referring to your graphs, predict the time for the counts/minute to be cut in half once again.

Q10 - Now use your graphs to check your prediction. How accurate was your prediction?

Q11 - How would you describe the way in which radioactivity changes with time?

The time required for the radioactivity of a source to decrease to half its former value is called its half-life.

Q12 - What is the half-life of the radioisotope which you used in this experiment?

Q13 - What was the advantage of plotting the data on semi-log graph paper?

EXPERIMENT 4-2

RADIOACTIVITY AND TIME #2

INTRODUCTION:

In the preceding experiment, we found the time required for the radioactivity of a sample to decrease to half its former value. We call this time the half-life of the sample. If we used a different source of radiation, would the half-life be the same? In this experiment we will repeat most of the procedure of Experiment 4-1 except we will use a different radioactive source.

MATERIALS NEEDED:

Minigenerator (Sr90/Y90)
G-M tube
Count rate meter (or scaler)
Timer
Planchet with concentric depressions
Ring stand and buret clamp
Safety tray and liner
Plastic gloves
Radiation warning labels
Heat lamp

PROCEDURE & INTERPRETATIONS:

Use the same equipment arrangement as in Experiment 4-1, except substitute a different radioactive source. Use a planchet with concentric depressions so the source will be localized in the center. Repeat the procedure of Experiment 4-1 until you have completed taking readings for 15 minutes.

Q1 - Did the count rates change in a fashion similar to Experiment 4-1?

Q2 - Was there a significant change in the count rate during the 15 minutes?

If the change wasn't significant, perhaps more time is necessary. So that it will not spill, place your planchet under a heat lamp and evaporate until dry. Don't heat so rapidly that spattering occurs. Place a piece of radiation warning tape, marked with your group number, directly over the planchet. This will warn of radiation and also cover the radioactive material so it will not rub off. See FIGURE 4-3.

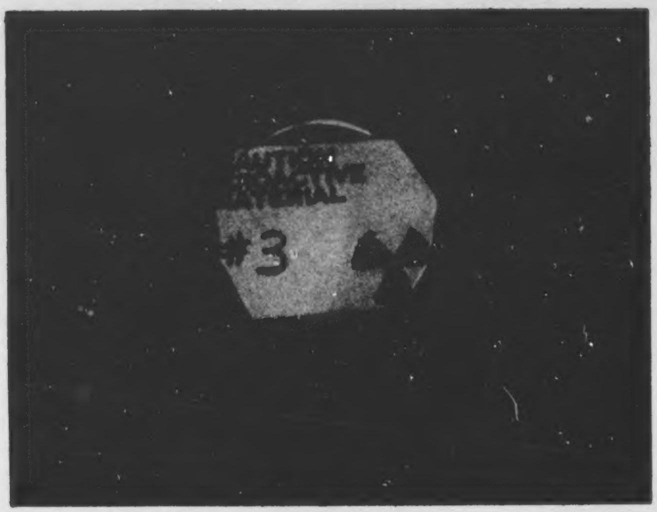


FIGURE 4-3

Place your sample under the G-M tube and carefully center it. Measure the height of the tube, above the planchet, and record it. Take a one-minute count on the sample and subtract the background count. Store your sample in the designated place.

After 24 hours again check the activity of your sample. Make certain the planchet and the G-M tube are in the same position as before.

Q3 - Is there now a significant change in the activity of your sample?

Measure the activity of the sample each day for 5 or 6 days.

Using a sheet of semi-log graph paper, plot a graph of corrected counts/minute versus time as you did in Experiment 4-1. If a weekend interrupted your measurements, be sure to set up the horizontal time scale to include these days. This will preserve the continuity of your graph.

Q4 - Is the shape of your graph similar to the Experiment 4-1 graph?

Q5 - If there is any difference, how do they differ?

Q6 - Can you determine the half-life of this sample? If so, what is it?

Half-life is a valuable tool in identifying unknown radioisotopes.

Q7 - Refer to Appendix D in the back of this book. Which radioisotopes do you think were used in Experiment 4-1 and Experiment 4-2?

Q8 - How many counts/minute would you predict for your source 10 days after you made the initial count in this experiment?

Q9 - If you measured the activity of a different sample every day for 5 days and found no significant change, what do you think might be the reason?

Q10 - Sample A has a half-life of 1 hour.

Sample B has a half-life of 10 hours.

An initial count is taken on each sample. One hour later each sample showed an activity of 400 c/m. Which sample had the highest initial count?

Q11 - How long after the activity was 400 c/m would Sample A show an activity of 100 c/m?

Q12 - How long after the activity was 400 c/m would Sample B show an activity of 100 c/m?

Q13 - Which sample presents the greatest disposal problem? Explain.

EXPERIMENT 4-3

RADIATION AND DISTANCE

INTRODUCTION:

We have determined that radiation exposure is affected by time. What other factors might affect the amount of radiation exposure from a given source? As an object is moved closer to a light, it is more brightly illuminated. Does radiation work the same way? If you double your distance from a radioactive source, what effect does it have on the radiation exposure which you received? Let's investigate the relationship between radiation and distance.

MATERIALS NEEDED:

Radioactive disc (gamma)
Scaler
G-M tube
Timer
Calibrated board for holding G-M tube and source

PROCEDURE & INTERPRETATIONS:

Set up the equipment as shown in FIGURE 4-4.

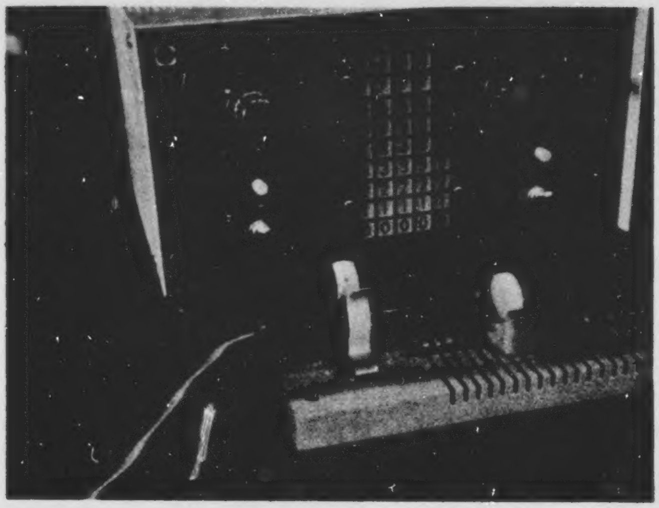


FIGURE 4 -4

With the G-M tube securely in place, take a background count. Prepare a data table for recording distance, counts, time, counts/minute, and corrected counts/minute. Leave a space to the right for adding two more columns of data. These will be used later.

Place your radioactive source on the calibrated board, 4 cm from the G-M tube. Take a count and record the necessary data. Move the course to a distance of 6 cm and repeat. Continue taking measurements at intervals of 2 cm until you reach a distance of 24 cm.

Plot a graph of corrected counts per minute versus distance.

Q1 - Does distance from the source affect the counts/minute?

Q2 - Does it change a little bit or a lot?

If we took a different source and measured the counts/minute at one distance, could we predict the counts/minute at another distance? Let's try.

If D is the distance from the sample to the source, calculate (using a calculator if available) the values for D^2. Record these in the first unused column in your data table. Calculate and record, in the other column, the values for $1/D^2$ (called the inverse square of D).

Q3 - When D doubles, what happens to the value of $1/D^2$?

Plot a graph showing counts/minute versus $1/D^2$.

Q4 - What is the general shape of the graph?

Q5 - What does a graph of this shape mean? If you don't know, discuss it with your instructor.

Now try to answer two questions asked earlier in this lab:

Q6 - If you double your distance from a radioactive source, what effect does it have on the radiation exposure which you receive?

Q7 - If the activity 10 cm from a source is 450 counts/minute, what would you predict for the activity 30 cm from the same source?

Q8 - Would the radiation become zero at very large distances? Explain.

Q9 - Which would reduce the radiation dose by a greater amount:

A. Cutting the time of exposure in half.

B. Doubling the distance from the source.

Q10 - A G-M tube, connected to a scaler, is placed 6 cm from a radioactive sample. In one minute, 400 counts are detected. If you placed the G-M tube 12 cm from the same source, how long should it take before 400 counts were detected?

* * * * * * * * * * *

In the past three experiments, we have investigated the effects of time and distance on radiation exposure. What other factors should be considered? Is the material between us and the source important? We have already seen that alpha radiation cannot penetrate even a sheet of paper. Not much would be gained by investigating the penetration of alpha particles any further. In the next two experiments we will investigate the ability of beta and gamma radiation to penetrate various materials.

EXPERIMENT 4-4

BETA SHIELDING

INTRODUCTION:

What material makes a good shield for beta radiation? How does beta penetration vary with shield thickness? We will measure beta penetration through cardboard, lead, and aluminum in an attempt to answer these questions.

MATERIALS NEEDED:

Radioactive disc (beta)
G-M tube
Scaler
Timer
Cardboard sheets
Aluminum sheets
Lead sheets
Calibrated board
Vernier caliper or micrometer
Graph paper
Semi-log graph paper

PROCEDURE & INTERPRETATIONS:

Set up the equipment as in FIGURE 4-5. After the equipment has warmed up, take a background count (source removed). With no shield in place, position the source on the calibrated board so that you obtain a strong initial count. Leave the source and G-M tube in this position throughout the remainder of the experiment.

Set up a data table for recording time, counts, counts/minute, corrected counts/minute, shield material, and shield thickness. Measure and record the thickness of a cardboard, a lead, and an aluminum shield. Determine the counts/minute with no shield in place. Repeat using a shield consisting of 2 sheets of cardboard. Then use 4, 6, 8,... up to 20 sheets of cardboard, recording all values in your data table. Repeat using aluminum instead of cardboard. This time use 1, 2, 3,... sheets of aluminum. Any time it becomes difficult to distinguish your count from the background count you may stop taking measurements. Repeat using lead in place of the aluminum.

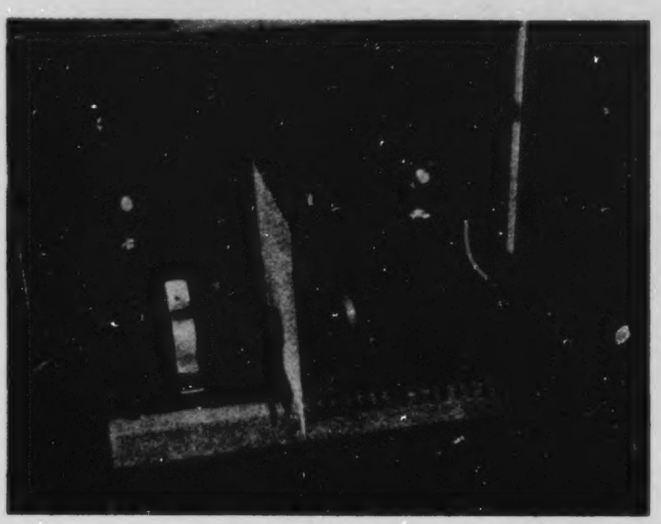


FIGURE 4-5

On the same set of axes, plot the corrected counts/minute versus thickness for both the aluminum and the cardboard.

Q1 - By comparing graphs, determine how the shielding abilities of aluminum and cardboard compare.

Q2 - How many sheets of cardboard would be necessary to absorb as much radiation as one sheet of aluminum?

Try plotting the data from the cardboard on semi-log graph paper.

Q3 - What (if any) advantage does the semi-log paper have?

Q4 - What thickness of cardboard will stop half the beta radiation? (This is called the half-thickness.)

Q5 - What is the half-thickness of aluminum for your beta radiation?

EXPERIMENT 4-5

GAMMA SHIELDING

INTRODUCTION:

We have previously determined that gamma radiation is more penetrating than either alpha or beta. How much greater is its ability to penetrate than beta? In this experiment we will repeat much of the procedure from last experiment, except we will use a gamma rather than a beta source.

MATERIAL NEEDED:

Radioactive disc (gamma)
G-M tube
Scaler
Timer
Aluminum sheets
Lead sheets
Calibrated board
Vernier caliper or micrometer
Graph paper
Semi-log graph paper

PROCEDURE & INTERPRETATIONS:

Set up the equipment just as you did in the last experiment. Prepare a data table with the same headings as last experiment. Record the background count.

Place the gamma source 16 cm (or at a distance which gives a strong initial count) from the G-M tube and record the corrected counts/minute with no lead shields in place. Determine the radiation (corrected counts/minute) that penetrates 2, 4, 6,...20 lead shields. Record the thickness of one sheet of lead.

Repeat the procedure using 10, 20, 30,...80 aluminum shields. Record the thickness of one sheet of aluminum.

Plot a graph of radiation (corrected counts/minute) versus lead thickness. (Use either regular or semi-log graph paper, whichever you think would be easiest to interpret.) On the same set of axes plot a second graph of radiation versus aluminum thickness.

Q1 - Looking at the graphs, what do you conclude about lead as a shield compared to aluminum?

Q2 - How many sheets of aluminum equal the shielding ability of 1 sheet of lead?

Q3 - What thickness of aluminum would shield half the gamma radiation? (You may have to extend your graph to determine this. The process of extending a graph to predict values outside the measured range is called extrapolation.)

Q4 - How does this compare with the half-thickness of aluminum for the beta radiation in the last experiment?

Q5 - What is the half-thickness of lead for your gamma source?

Q6 - How does this compare with the half-thickness of lead for beta radiation in the last experiment?

Q7 - If you are using 6 sheets of aluminum in the experiment, does it make any difference whether they are close together or if there are air spaces between them? If you aren't sure, make a prediction and then try it both ways.

Q8 - By extrapolating, can you predict what thickness of lead would completely shield the source?

* * * * * * * * * *

Let's summarize the results of the past five experiments. Several factors affect the amount of radiation exposure from a source.

1. Time - In general, twice the exposure time will give us twice the radiation dose. This may not be true, however, if the radioactive source has a short half-life. In that case the dose rate decreases as time goes on. The total dose, however, continues to increase.
2. Distance - Distance is an extremely important factor. Dose rate and distance are related by an inverse square law. Doubling the distance from the source will decrease the dose rate to ¼, tripling the distance reduces the dose rate to 1/9, etc.
3. Shielding - The thickness as well as the material comprising the shield is important. In general, more dense materials form more effective shields.
4. Type of radiation - Gamma radiation is by far the most penetrating and is reasonably difficult to shield. Alpha and beta radiations are both shielded against quite easily.

In general, when working with very "hot" sources, be aware of the type of radiation and use effective shielding for the type of radiation that exists. Work at as large a distance as possible and keep exposure time to a minimum. Film badges and dosimeters should be worn to check exposure.

Now let's return to our consideration of shielding.

EXPERIMENT 4-6

BACK SCATTERING

INTRODUCTION:

In the last two experiments we saw the effects of shielding or absorption on different types of radiation. What do the words shielding and absorption imply? Does radiation bounce? Is it completely absorbed like liquid in a sponge? It is hoped that this experiment will answer these questions.

MATERIALS NEEDED:

Radioactive disc (beta)
Scaler
G-M tube
Timer
4 Lead shields
1 Aluminum shield
1 Cardboard shield
Calibrated board

PROCEDURE & INTERPRETATIONS:

Position the G-M tube and the lead partition as shown in FIGURE 4-6. Take a 5-minute count on each of the following:

A. Background radiation. Have the partition (3 sheets of lead between the source and the G-M tube), but neither the source nor the scattering shield in place.

B. Same as above with source added.

C. With one cardboard scattering shield in place.

D. With one aluminum scattering shield in place

E. with one lead scattering shield in place.

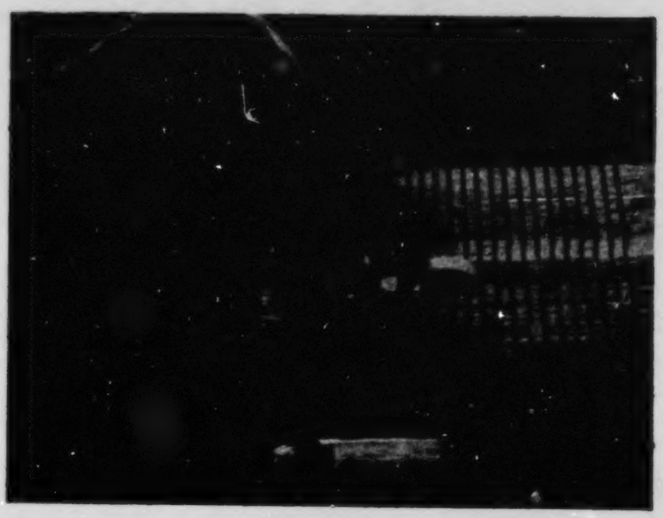


FIGURE 4-6

Q1 - How do the readings from trials A and B compare?

Q2 - Did radiation penetrate the lead partition?

Q3 - How do the last three readings compare with the second?

Q4 - How can you explain the difference? (If any)

Q5 - Do all the scattering shields affect the radiation in the same way?

Q6 - From your data, which shield, if any, caused the most back scattering (reflection)?

* * * * * * * * * * *

Perhaps one other factor should be considered in determining radiation exposures. We have just studied back scattering. What about other types of scattering? We can direct a light beam by shining it through a shiny metal tube. Can we direct radiation by allowing it to travel through a tube? Let's try it.

EXPERIMENT 4-7

COLLIMATION

INTRODUCTION:

You have shown that beta radiation can back scatter off different materials. What other type of scattering occurs and what things affect it? To investigate this you will set up the equipment in a somewhat different manner.

MATERIALS NEEDED:

Radioactive source (beta)
Scaler
G-M tube
Timer
Ringstand and clamp
Lead scattering tube
Aluminum scattering tube
Cardboard scattering tube

PROCEDURE & INTERPRETATIONS:

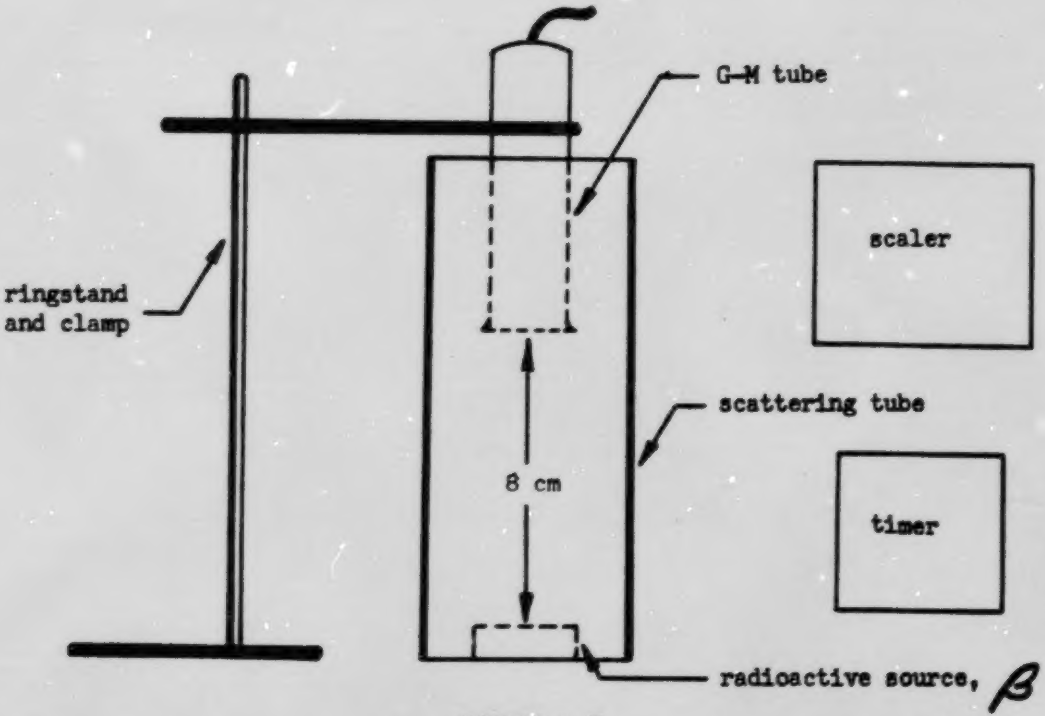

G-M tube
scaler
ringstand and clamp
scattering tube
8 cm
timer
radioactive source, β

FIGURE 4-7

Set up the equipment as shown in FIGURE 4-7 with neither the cylinder nor source in place. Measure and record the background count. Place the source under the G-M tube as shown in FIGURE 4-7. Take a 2-minute count. Place the lead tube over the source, and the G-M tube inside the lead tube. Make sure to retain the 8 cm distance between the source and G-M tube. Take a 2-minute count. Repeat this procedure using the aluminum tube and then using the cardboard tube.

Q1 - Which tube produced the greatest amount of collimation (scattering)?

Q2 - What things determine the amount of scattering?

Q3 - How is collimation related to back scattering?

Q4 - With a G-M tube 8 cm from a radioactive source, how would you position a lead sheet and a lead tube to obtain the maximum count?

* * * * * * * * * * *

Now that we have a pretty good idea of what factors affect the amount of radiation received, let's consider some units of measurement.

If we wish to measure the length of something we use a unit such as the foot, the meter, or the mile. If we wish to measure volume of something we use a unit such as the quart, the liter, or the gallon.

What if we wish to measure the activity of a radioactive source, or the amount of radiation striking an object, or the amount of radiation absorbed by that object? Are there units for measuring these things?

First, let's consider the activity of the source.

EXPERIMENT 4-8

AMOUNT OF RADIATION

INTRODUCTION:

Earlier studies have shown that radiation and samples of radioactive materials are not all the same. While they all affect photographic film or G-M tubes, they do not behave the same when an absorber or shield is used. Is this the only way in which these samples differ? Do all samples produce the same number of radiated particles? Is there some way in which these characteristics can be described?

MATERIALS NEEDED:

1 Radioactive sample (per group)
Scaler
G-M tube
Timer
Ring stand and clamp to support G-M tube
2 or 3 unknown samples (per class)

PROCEDURE & INTERPRETATIONS:

Your instructor will supply you with a numbered sample of radioactive material. Each group's sample contains a different quantity of the same radioactive element. Arrange the materials as shown in FIGURE 4-8.

FIGURE 4-8

Measure and record the background radiation. Check your sample's radiation activity and record this information in a table. Pass your samples around the class until you have measured each sample's activity. Be sure that on each count your sample is carefully centered on the G-M tube. Leave room at the right of the table for additional columns should the need arise. (Be sure to subtract the background count from the readings.)

Q1 - Which sample gave the highest count?

Q2 - Which sample gave the lowest count?

Arrange the data in a second table so that the counts are listed in ascending order.

Q3 - Can you find any relationship among the counts? (Does the count double as you go from one to the next? Is it cut in half? Is there a common factor relationship?) Divide all counts by the lowest count and record in an added column.

Suppose the activity of the least active sample were given a name. Let's call it the eiruc. The activity of the least active sample is 1 eiruc.

Q4 - How many eirucs of activity did each of the other samples have? (Expand the data table to include this information.)

Q5 - Suppose we had a sample with twice the activity of the least active sample. How many eirucs of activity would it have?

Q6 - How many eirucs of activity would a sample contain if it were only half as active as the least active sample?

Measure the activity of one of the unknown samples.

Q7 - Express the activity or the unknown in eirucs.

Q8 - Could you express the activity of any sample in eirucs?

Q9 - Define an eiruc.

* * * * * * * * * * *

The eiruc is a unit of activity which has meaning only to those in this class. If you tried to communicate with someone outside the class and tell him to prepare a source with 5 eirucs of activity it wouldn't be clear what you meant. However, you could prepare a 5 eiruc source with no problem.

It would obviously be desirable to have a unit of activity which means the same thing to everyone. This is true of any type of measure. As an example, for many centuries the foot was a unit of measure equal to the length of a man's foot - any man's foot. As more precision was needed, however, it became necessary to establish a standard foot measure so it would mean the same to everyone.

A standard unit of radiation activity has been established. It means the same thing to everyone and it is called the curie. (Notice that curie is eiruc spelled backwards - or is eiruc curie spelled backwards?) Since not all counters have the same kind of tube or count in the same way, the meter count cannot be used to establish a standard. So, let's consider another method.

Each time radiation is emitted from an atom we say the atom undergoes a "disintegration." We could, therefore, define our standard unit of activity as being equal to a certain number of disintegrations per second (d/s). The number which has been selected to define the curie is 37 billion disintegrations per second. (3.7×10^{10} d/s). This is approximately the activity of 1 gram of pure radium.

In summary: 1 curie = 3.7×10^{10} d/s

Does the activity of a sample change with time? If you recall the radiation and time experiments which dealt with half-life, you know it must. If you have 1 curie of a radioactive substance now, you will have less than a curie a year from now. (For example, if the half-life of your 1 curie sample is 6 months, in one year you will have a $\frac{1}{4}$ curie sample of that material.

Exercise 4-1:

a. A radioactive sample undergoes 3.7 X 10^4 d/s. Express the sample's activity in curies.

b. A microcurie (μc) is defined as one-millionth (10^{-6}) of a curie. Express your answer from Part A in μc.

c. A sample has an activity of 7.4 X 10^7 d/s. Express this activity in curies and in microcuries.

d. A sample has a half-life of 5 days and an initial activity of 20 μc.

What is its activity (in μc) after: 5 days
10 days
15 days

e. What would the activity of the Part D sample (in d/s) after 15 days?

To determine the activity of a sample in curies, we must know the number of disintegrations/second. How does this relate to the count rate (counts/second) which we can determine using a G-M tube and scaler? We will have to determine something about the direction the radiation is traveling.

EXPERIMENT 4-9

GEOMETRY OF RADIATION

INTRODUCTION:

Up until this time we have considered radiation traveling in one direction only. We have done little to consider what directions radiation travels or what portion of the total radiation we are actually measuring. These two areas relate to the "geometry" of the system. With the aid of the radiation sphere, we will study these two aspects of radiation. At the center of the radiation sphere there is a source of gamma radiation.

MATERIALS NEEDED:

Radiation sphere
Scaler

End window G-M tube
Timer
Ruler

PROCEDURE & INTERPRETATIONS:

Notice on the radiation sphere that there are the numbers 1 through 8 placed at various locations. You are to measure and record 5 minute counts at five of these locations. See FIGURE 4-9. Do the same thing for one location of your own choice. Convert each reading to corrected counts/minute.

Q1 - How do these six readings compare?

Q2 - Do you think there would be any point on the sphere where the radiation would be significantly larger?

Q3 - Find the average of your six readings. Divide each reading by the average. How do your values compare with others in the class?

Q4 - In what direction, or directions, is the radiation traveling from the source?

Q5 - What do the results tell you about the amount of radiation as the direction changes?

Q6 - What does the amount of measured radiation depend on?

Q7 - Since radiation is moving out in all directions, how would it be possible to obtain a measure of the total radiation coming from the source?

From looking at FIGURE 4-10, you can see that the only radiations that can be counted are those which strike the G-M tube. All other radiation moving away from the source is undetected. Thus, the radiation that you counted is only the radiation that entered the end window of the G-M tube.

Q8 - If the end window were four times larger, how would this affect the radiation counted?

Q9 - If the end window were 10 times larger, how would the radiation count be affected?

Q10 - How large would the area of the end window have to be in order that all the points on the sphere would be covered?

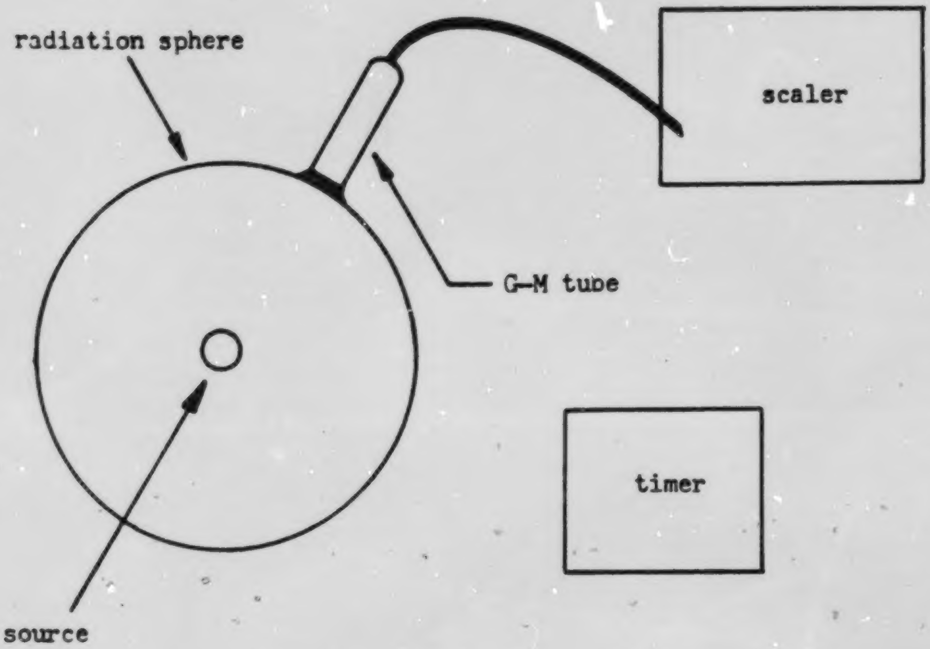

radiation sphere
scaler
G-M tube
timer
source

FIGURE 4-9

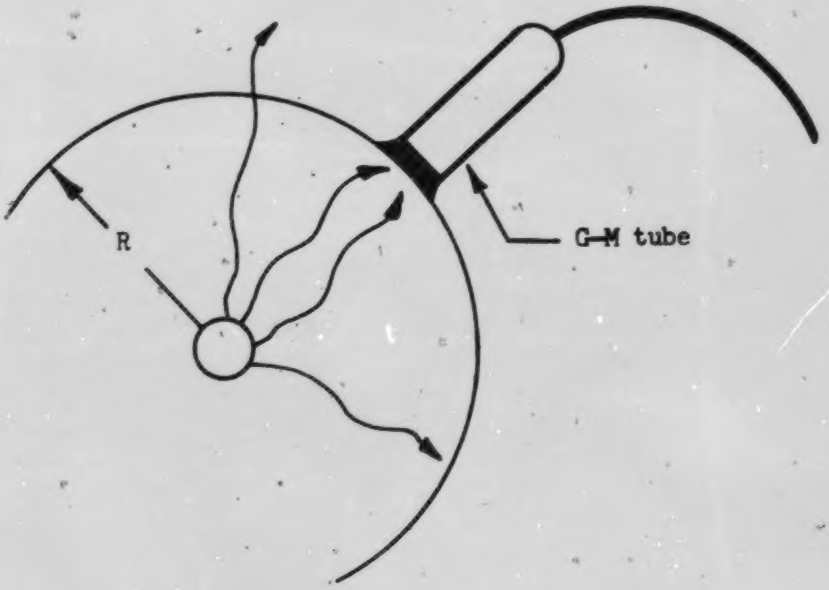


FIGURE 4-10

Since you do not have a large wrap-around window, you will have to use another technique to determine what percent or portion of the radiation the G-M tube is measuring.

Q11 - If you know the area of the end window and the total surface area of the radiation sphere, how could you determine the percent of radiation measured?

The area of the end window can be calculated by measuring its diameter and using the following equation:

Area of end window = $\frac{\pi d^2}{4}$, where d is the diameter of the end window, and $\pi = 3.14$.

Q12 - What is the area of the end window on the G-M tube you used?

Q13 - The formula for the surface area of a sphere is: Area = $4\pi R^2$, where R is the radius of the sphere. What is the surface area of the radiation sphere you are using?

Q14 - What is the ratio of area of the end window to the surface area of the sphere?

Q15 - What is this fraction in percent?

Q16 - What percent of the radiation passing through the ball is the G-M tube measuring? (Assume that each particle or ray which enters the G-M tube is counted.)

Q17 - Assuming the G-M tube is counting each particle or ray which enters it, how does the measured counts/minute (c/m) compare with the disintegrations/minute (d/m) of the source?

Q18 - Express the activity of the source in curies. (NOTE: It will be a very small fraction of a curie.)

Q19 - If your G-M tube detected 5×10^{10} counts/minute at the surface of the sphere, express the approximate activity of the source in curies. (Again assume that each particle or ray which enters the G-M tube is counted.)

* * * * * * * * * * *

Now let's consider some more units of measure used in working with radiation. We have already defined the curie which measures the activity of the source and is equal to 3.7×10^{10} d/s.

Since radiation travels out in all directions from a source, we are usually concerned with our exposure to radiation rather than the total activity produced. In Chapter II, the roentgen was defined. The precise definition can be found in the glossary. For the present, just keep in mind that it is a measure of the ionizing effect of gamma or X-rays on a small volume of dry air. Notice that the roentgen is a measure of the effect of the radiation rather than the original amount.

A similar unit is the rad (radiation absorbed dose). Unlike the roentgen, the rad can be used for any type of radiation. Instead of being defined in terms of ion pairs produced in dry air, the rad is defined as an amount of energy which any exposed material absorbs from the radiation. Again, a precise definition is in the glossary.

One final factor must be considered. The rad, which we have just discussed, measures the amount of energy absorbed from radiation. However, different types of radiation may produce different biological effects, even though the amount of absorbed energy is the same. Another unit called the rem (roentgen equivalent man) takes this into account.

Each type of radiation is assigned a factor called the RBE (Relative Biological Effectiveness). This factor takes into account the biological damage which a particular radiation will produce when it is absorbed. The dose in rems is found by multiplying the dose in rads by the RBE factor.

$$\text{rems} = \text{rads} \times \text{RBE}$$

For most beta and gamma radiation the $\text{RBE} = 1$, therefore, the dose in rems equals the dose in rads for beta and gamma radiation. The RBE for alpha radiation, however, ranges from 10 to 20. Therefore, if a particular alpha radiation with an RBE = 10 produced a dose of 5 rads, it would mean that 5 X 10 or 50 rems dose resulted. No wonder it can be so damaging when an alpha source enters the body.

It is helpful to remember that in soft tissue the dose of gamma radiation in rads or rems is roughly equivalent to the dose in roentgens.

Now let's summarize by looking at the definition of each of the units just discussed:

1. Curie (Abbreviation Ci or c). The basic unit to describe the radioactivity of a sample of material. The curie is equal to 37 billion disintegrations per second, which is approximately the rate of decay of 1 gram of radium. A curie is also a quantity of any nuclide having 1 curie of radioactivity. Named for Marie and Pierre Curie who discovered radium in 1898.
2. Roentgen (Abbreviation r). A unit of gamma or X-ray exposure that will produce 2.083 X 10^9 ion pairs per cubic centimeter of dry air at standard temperature and pressure. Named for Wilhelm Roentgen who discovered X-rays in 1895.
3. rad. The basic unit of absorbed dose of ionizing radiation. A dose of one rad means the absorption of 100 ergs of radiation energy per gram of absorbing material. (NOTE: The erg is a basic unit of energy.)
4. rem. The unit of dose of any radiation which produces the same biological effect as 1 rad of X-rays. The dose in rems = dose in rads X RBE. (NOTE: The RBE is a factor which compares the biological damage of various radiations compared to an RBE = 1 for X-rays.)

Exercise 4-2:

a. A person receives a radiation dose of 3 rads. Determine his dose in rems

117

if the radiation was from: gamma rays

alpha particles (RBE = 15)

b. An alpha and a beta source each enter a person's body. Each produces the same number of rads of ionizing radiation per day. Which produces the highest dose in rems per day?

c. A person is exposed to 2 roentgens of gamma radiation. What is his approximate dose in rads? In rems?

In Chapter III, we discussed both the long term and short term dangers of exposure to radiation. Now we have considered factors which affect the degree of such exposure; things such as time, distance, shielding, and the type and strength of the source. We have also learned some units for measuring the amount of exposure; the roentgen, the rad and the rem.

Now we are ready to consider the question: How much radiation exposure is too much? There is no single, clear cut answer. The following are some questions to be considered in trying to establish safety standards for external radiation exposure:

1. How much of the body was exposed? Small areas can receive a much higher dose than the entire body.
2. How penetrating was the radiation? A person could obviously survive more exposure to beta radiation than gamma radiation.
3. What part of the body was exposed? The hands, for example, could withstand a much higher dose than some vital organ.
4. Over how much time did the exposure occur? A large single dose can be much more serious than an equal dose spread over a long period of time. When the dose is spread out, the body may have sufficient time to replace damaged cells with no obvious ill effects.
5. What was the age of the person receiving the exposure? There are some

cumulative effects, particularly genetic damage. The reproductive organs of a young person should not receive unnecessary exposure to radiation. Considering all these and other factors, radiologists and health physicists are generally agreed upon a set of standards for the maximum permissible radiation dose for radiation workers. If these limits are observed the individual should not suffer any ill effects and the probability of genetic damage should be minimal.

FIGURE 4-11 lists generally accepted standards or controls:

MAXIMUM PERMISSIBLE DOSE FOR RADIATION WORKERS

1. Whole body penetrating radiation (gamma)

   Cumulative lifetime dose: (Persons Age - 18) X 5 rems

   Calendar Quarter (3 month) dose: 3 rems

   Student Exposure rate: .3 rem/year
   .01 rem/experiment

2. Derma or Skin Dose (beta + gamma)

   Calendar year dose = 10 rems

   Calendar quarter dose = 3 rems

3. Extremeties (hands, forearms, feet, and ankles) beta + gamma

   Calendar year dose = 75 rems

   Calendar quarter dose = 25 rems

FIGURE 4-11

Exercise 4-3:

a. What is the maximum permissible accumulated dose (whole body penetrating radiation) for a person 38 years of age?

b. A person receives a 3 rem skin dose in January, another 3 rem skin dose in April, and another 3 rem skin dose in July. How soon could he receive another 3 rem dose without exceeding the above controls?

c. A person 28 years of age has accumulated a lifetime dose of 30 rems What would be his maximum allowed dose during the next 12 months? (whole body penetrating radiation)

d. In our society we deal with many things which can be both beneficial and harmful. As an example, consider the following question: Has the widespread use of the automobile caused a longer or shorter lifespan in the average individual? Be prepared to discuss in class.

e. List things which you could do, while working around radioactive materials, to minimize your exposure to radiation.

CHAPTER V

A LITTLE RADIATION PHYSICS

We have seen that material does not become radioactive by being subjected to alpha, beta, or gamma radiation from a radioactive material. We do know that things can be made radioactive and we should have some idea of how this comes about. In order to do this, we should study a little more about the structure of the atom.

Earlier we discussed the atom and arrived at a very simple model. The atom consists of a dense, hard, small, positively charged nucleus which is surrounded at quite some distance by negatively charged electrons having practically no weight at all. The nucleus contains protons which are positively charged and neutrons which have about the same weight as a proton but have no charge (neutral). In a neutral atom, for each positively charged proton in the nucleus there is a negatively charged electron in orbit outside the nucleus.

The number of protons in the nucleus (called the atomic number) identifies the atom and determines its fundamental properties. For example, all atoms which have 1 proton in the nucleus have the same chemical properties. We call these atoms hydrogen. Thus, each atom of the element hydrogen has one proton in its nucleus. In nature we find elements containing 1 to 92 protons per atom.

The number of neutrons in the nucleus may range fron none to almost 150. In the case of certain elements, we find that different atoms of the same element have the same number of protons but have a different number of neutrons. These atoms are called isotopes. For example, three isotopes of hydrogen are known. One isotope contains one proton and no neutrons in the nucleus and is called hydrogen. Another contains one proton and one neutron in the nucleus and is called deuterium. Finally, the other, called tritium, contains 1 proton and 2 neutrons in its nucleus.

Since we realize that a proton and a neutron have about the same weight and the electron's weight is negligible, it is evident the weights of the isotopes of the same element will be different. Thus, one hydrogen atom will have a weight of one proton. Another will have a weight of one proton and one neutron (twice the weight of a proton). The other has a weight of one proton and two neutrons (three times the weight of a proton). The weight of an atom is called its atomic weight. The atomic weight of an atom is the sum of its protons and neutrons. Thus, the atomic weights of the isotopes of hydrogen are 1, 2, and 3 respectively.

Exercise 5-1:

Substance X is known to have 17 protons and 18 neutrons, substance Y has 17 protons and 19 neutrons, and substance Z has 17 protons and 20 neutrons.

a. What is the atomic number of X? Of Y? Of Z?

b. What is the atomic weight of X? Y? Z?

c. How many electrons would the neutral atoms of X have? Y have? Z have?

d. Are the substances the same or different elements?

e. What are substances X, Y, and Z called?

Some of the isotopes of certain elements are radioactive. In the next experiment, we shall study the properties of the element indium.

EXPERIMENT 5-1

PRODUCTION OF INDIUM HYDROXIDE WITH AND WITHOUT RADIOACTIVE INDIUM

INTRODUCTION:

In the first part of this experiment we will observe the results when non-radioactive indium, in the compound indium chloride ($InCl_3$), reacts with a non-radioactive compound, ammonium hydroxide (NH_4OH). In Part II we will use indium chloride that contains a radioactive isotope of indium. Will there be a difference in chemical behavior in these two reactions?

MATERIALS NEEDED:

G-M tube and scaler
$InCl_3$ solution (non-radioactive)
NH_4OH solution
2 test tubes (18 x 150mm)
1 graduate (10 or 25 ml)
1 25 ml (or 50 ml) beaker
1 funnel
2 planchets (or index cards)
$Sn113/In113^m$ minigenerator
2 sheets of filter paper
1 forceps
Safety tray and liner
Plastic gloves

PROCEDURE & INTERPRETATIONS:

PART I

A. Measure carefully 5 ml of ammonium hydroxide solution (NH_4OH)

B. Measure carefully 2 ml of indium chloride solution ($InCl_3$) and add it to the test tube. Thoroughly mix the contents and let the mixture stand for 3 minutes.

C. Filter the solution from the test tube, collecting the liquid (filtrate) in a 25 ml beaker.

D. Wash the precipitate (the solid in the filter paper) with 10 ml of distilled water collecting the washings in the 25 ml beaker.

E. Remove the filter paper carefully with a forceps and place it on an index card or a planchet.

F. Record your background count.

G. Measure the activity (counts/minute) of both the filtrate and the precipitate.

H. Record the readings in your lab notebook.

I. Mark your precipitate and save it to compare with Part II.

PART II

A. Clean all of the equipment used in Part I.

B. Place 5 ml of ammonium hydroxide solution in a test tube.

C. Add 5 drops of eluant from the minigenerator and observe very carefully. This eluant contains radioactive indium chloride.

D. Add 2 ml of indium chloride solution and thoroughly mix the contents. Since we have a limited supply of radioactive indium chloride, we are adding non-radioactive indium chloride to produce the same amount of precipitate as in Part I. Let the mixture stand for about 3 minutes.

E. Filter the solution from the test tube, collecting the filtrate in a 25 ml beaker.

F. Wash the precipitate as in Part I.

G. Remove filter paper as in Part I.

H. Measure the activity of both the filtrate and the precipitate and record your readings.

I. Observe and compare the precipitates from Part I and Part II.

Q1 - What visible change took place when indium chloride was added to ammonium hydroxide?

Q2 - Did any of the radioactive indium chemically combine to form a precipitate? How do you know?

Q3 - Was there any radioactive indium that did not combine when the ammonium hydroxide was added to the solution? How do you know?

Q4 - Comparing the reaction in Part I to Part II, do you think that a radioactive isotope behaves similarly to a non-radioactive isotope? Did the indium hydroxide (the precipitate) appear to be the same in each case?

Q5 - In view of your answer to Q4, can you think of any practical applications of this technique?

* * * * * * * * * * *

If we look at the chemical reaction in Part I and Part II, we may be able to analyze what has happened in this experiment.

PART I

$InCl_3$ solution + $3NH_4OH$ solution $\rightarrow$ $In(OH)_3$ solid + $3NH_4Cl$ solution

PART II

Let In^* be the symbol for radioactive indium.

In^*Cl_3 solution + $3NH_4OH$ solution $\rightarrow$ $In^*(OH)_3$ solid + $3NH_4Cl$ solution

Thus, the two isotopes behave in an identical manner chemically.

The element uranium contains isotopes which will react chemically in the same way. Therefore, to the chemist, a mass of material consisting of these isotopes is uranium. In any chemical combination, we are dealing with reactions of atoms and these reactions are dependent upon the number of external electrons. The nucleus remains intact.

Now we should focus our attention on the nucleus itself. How is the nucleus put together? What particles are found inside the center of the atom? A study of radioactive substances will supply major clues in answering these questions. Consider what happens when a radioactive isotope gives off radiation.

MINI EXPERIMENT 5-2:

Given samples of uranium ore, determine if they are radioactive. If so, what kind of radiation is given off?

* * * * * * * * * * *

One of the isotopes in uranium ore is uranium 238. Uranium 238 has 92 protons and 146 neutrons. Uranium 238 emits an alpha particle. An alpha particle consists of two protons and two neutrons. It is identical to the nucleus of a helium atom. With the loss of two protons and two neutrons, the nucleus now has 90 protons and 144 neutrons. Its atomic weight is now 234. Since the number of protons has changed, it is no longer uranium but a different element called thorium.

Thorium 234 does not emit an alpha particle from its nucleus but does emit a beta particle. Recall that a beta particle is identical to an electron. Where does the beta particle come from? The nucleus contains protons and neutrons. A neutron under appropriate conditions will sometimes change into an electron and a proton. If we use this model, we can see that if a beta particle (an electron) is ejected from the nucleus, the nucleus will now have one more proton than it had before beta emission. Therefore, when thorium emits a beta particle, the remaining nucleus has 91 protons and 143 neutrons. We have, in effect, added one proton and subtracted one neutron. The atomic weight is still 234. But since the number of protons has changed, we have a new element, protactinium.

A summary of what we have discussed thus far is shown in FIGURE 5-1.

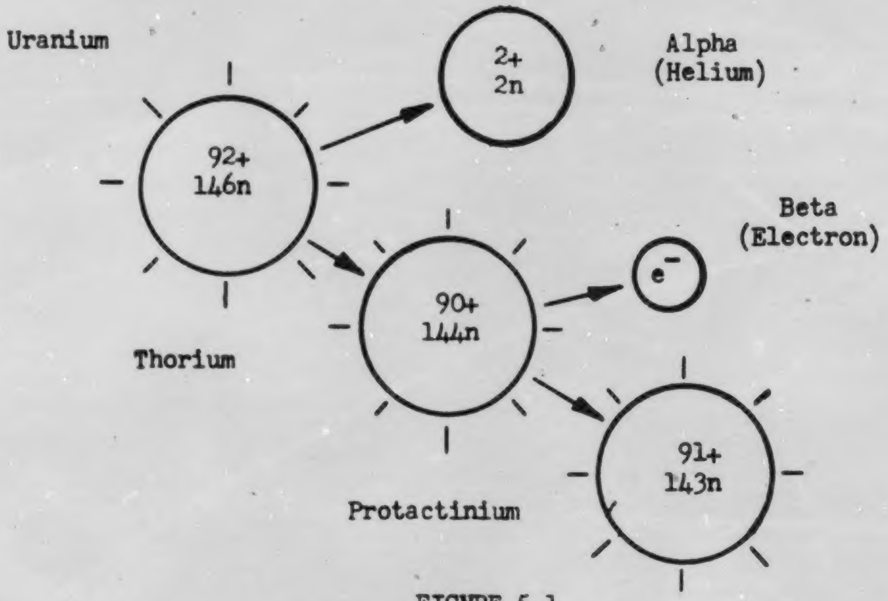


FIGURE 5-1

Exercise 5-2:

Complete the following table. You will have to use Appendix C to determine the names of the elements.

Name of the Element	Atomic Weight	Type of Radiation Emitted	Number of Protons	Number of Neutrons	Half-life
Uranium	238	Alpha particle	92 - 2	146 - 2	4.5×10^9 y
Thorium	234	Beta particle	90 + 1	144 - 1	24.1 d
Protactinium	234	Beta particle			1.17 m
		Alpha particle			2.5×10^5 y
		Alpha particle			8.0×10^4 y
		Alpha particle			1,620 y
Radon	222		86 - 2	136 - 2	3.82 d
		Alpha particle			3.05 m
Lead	214		82 + 1	132 - 1	26.8 m
		Beta particle			19.7 m
		Alpha particle			1.6×10^{-4} s
		Beta particle			19.4y
Bismuth	210		83 + 1	127 - 1	5.0 d
		Alpha particle			138 d
Lead	206	Stable Atom	82	124	Stable

Note that Lead 206 is stable and not radioactive. We have reached the end of the line.

FIGURE 5-2

Exercise 5-3: (Refer to FIGURE 5-2)

a. Would a sample of Uranium 238 contain only Uranium 238, or would it be a mixture of other elements? Explain.

b. Consider uranium as the "parent" element in this series and the other decay product as "daughters." Which daughter, on the average, has the shortest existence? The longest existence?

c. One places a wire into a sample of radioactive Randon-222 gas. After several days the wire is examined and a small amount of solid has deposited on the needle. What elements could make up this solid?

This discussion has included what is known as the Uranium series. There are other naturally occurring series of radioactive decay that are known. They are called the Thorium, Actinium, and Neptunium series. Each is named for the "parent" of the chain. Also, very careful investigation has shown that there are several radioactive isotopes that are not members of any of these four series. Each of these isotopes have an extremely long half-life and a corresponding low activity per gram of material. This low activity makes the detection and the isotope identification very difficult. One example of this type of isotope is Carbon-14.

We have accounted for alpha and beta radiation, but what about gamma radiation? Where does it come from? Gamma radiation originates when the discharge of alpha or beta particles from the nucleus does not take sufficient energy with it to leave the nucleus in a "contented" state. If the particle leaving the nucleus does not take with it all of the energy that the atom would like to get rid of, it throws off some energy in the form of gamma radiation. An example is shown in FIGURE 5-3.

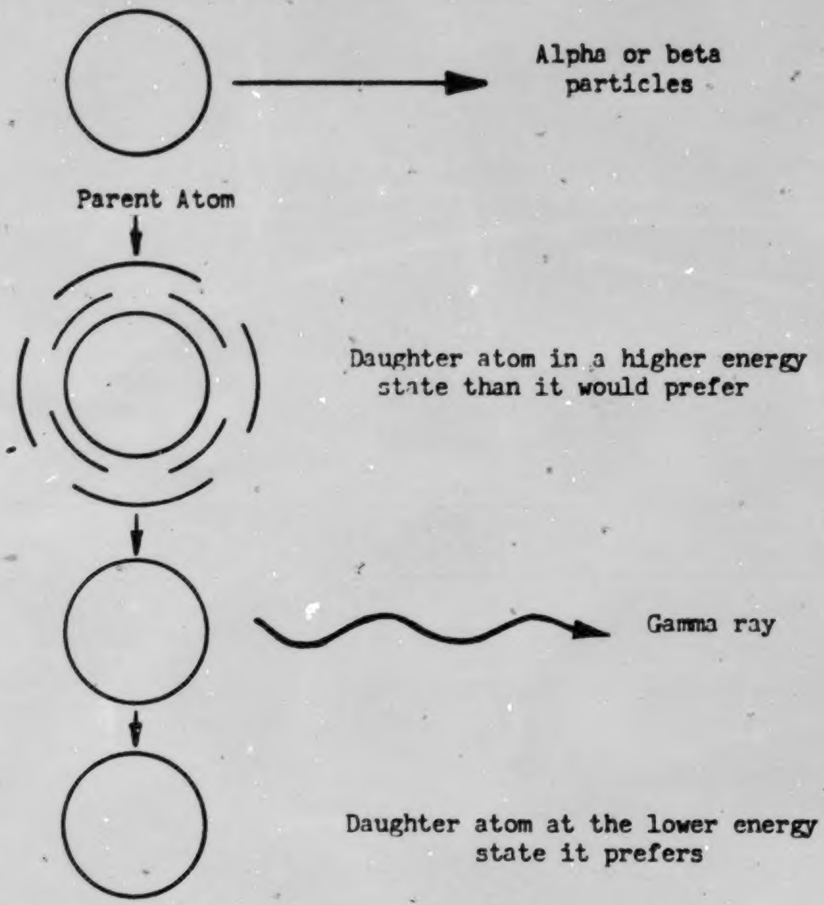

Alpha or beta particles
Parent Atom
Daughter atom in a higher energy state than it would prefer
Gamma ray
Daughter atom at the lower energy state it prefers

FIGURE 5-3

Exercise 5-4:

When the dials of watches used to be painted with a substance containing radium, a pure alpha emitter, on could detect this radiation through the watch crystal with a G-M detector. Why?

EXPERIMENT 5-3

SEPARATION OF RADIOISOTOPES

INTRODUCTION

Recall that when uranium-238 decays it produces a daughter, thorium-234.

The half-life of uranium-238 is 4.49×10^9 years while thorium-234 has a half-life of 24 days. Can we separate these isotopes from a uranium compound?

In this experiment, we shall use two techniques that take into account the differences in their physical properties. In Part I we shall attempt to see if they have solubility differences. In Part II we shall use a technique called paper chromatography. This technique uses the fact that some ions are separated by the differences in their rate of travel along a paper strip.

Use safety techniques for handling liquid isotopes.

MATERIALS NEEDED:

Uranyl nitrate (solid)
Uranyl nitrate (saturated solution)
Ammonium nitrate (saturated solution)
Ethyl acetate
Graduated cylinder
Planchets that will hold 1 ml
G-M detecting system
2 Pipettes, 1 ml per class
Syringe pipette
100 ml separatory funnel, 1 per class
Test tube with stopper to fit, 1 per class
2.25 ml beakers
Heat lamp
50% hexane-acetone by volume solution
Hydrometer jar about 12" to 18" high, about 2" diameter
Cork stopper to fit jar
Stirring rod
Whatman #1 Chromatography paper 1" wide
Common pin
Centimeter ruler
Safety tray and liner
Plastic gloves

PROCEDURE & INTERPRETATIONS:

PART I Differences in Solubility

Your instructor will perform each of the following steps:

A. Dissolve 3.9 g of uranyl nitrate in 15 ml of a saturated solution of ammonium nitrate solution.

B. Pour this solution into a separatory funnel that contains 60 ml of ethyl acetate.

C. Stopper the funnel and shake vigorously for about one minute.

D. Draw off the bottom layer of water and put it into a beaker. The beaker will be marked for identification.

E. Draw off the ethyl acetate into another beaker and label it.

Each group should pipette one ml of each solution into separate planchets that have been previously labeled for identification.

Place the planchets under a drying lamp and evaporate to dryness (avoid spattering).

FIGURE 5-4

Count each sample with and without a paper shield. See FIGURE 5-4. Due to the small amount of material, you may have to take longer than one-minute counts. Record your data.

Q1 - Are either or both samples alpha emitters?

Q2 - Are either or both samples emitting primarily alpha?

Q3 - Are either or both samples emitting beta radiation?

Q4 - Using the information from FIGURE 5-2, which sample is parimarily thorium? Primarily uranium?

PART II Chromatography

Make a right angle bend in a common pin. Stick the pin into the center of the bottom end of the cork stopper as shown in FIGURE 5-5.

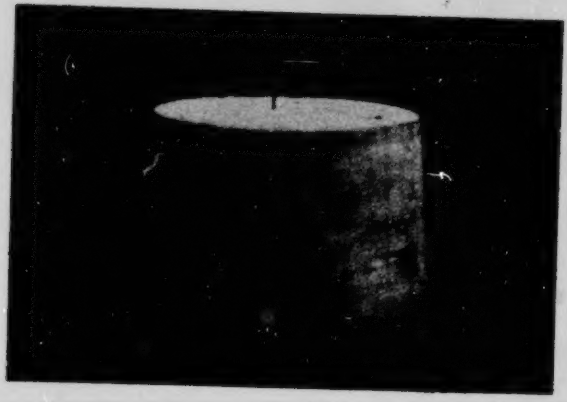


FIGURE 5-5

Estimate the length of chromatography paper you will need to hang on the pin so the end of the strip will be within 2 cm of the bottom of the jar. Cut the paper. Hang the paper on the pin and check to see if your length is correct. If not, adjust.

Take out your paper and using a lead pencil draw a line about 3 cm from the bottom edge. (Do not use a pen.) Mark lines, one centimeter apart, on the paper and label them zero (the line nearest the bottom), 1, 2, 3,... 20 as shown in FIGURE 5-6.

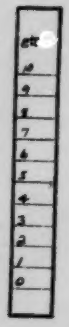


FIGURE 5-6

Using a stirring rod, place a spot of uranyl nitrate solution on the center of the zero (start line) of the strip. Place under a heat lamp until dry. Add a second drop and dry. Take a count, on the spot, with the G-M tube about 1 cm away. If necessary, add additional drops, by the above procedure, until at least 500 c/m is reached.

While one partner is preparing the strip, the other can add the acetone-hexane solution to the jar to a depth of about 3 cm. Stopper the jar until you begin the next step.

Hook the paper strip onto the pin in the cork stopper. Carefully lower the paper into the jar until the end of the strip extends about 1 cm into the solution. Do not get the spot in the solution. Adjust the length of the strip if necessary. Do not let the strip touch the edge of the glass. See FIGURE 5-7.

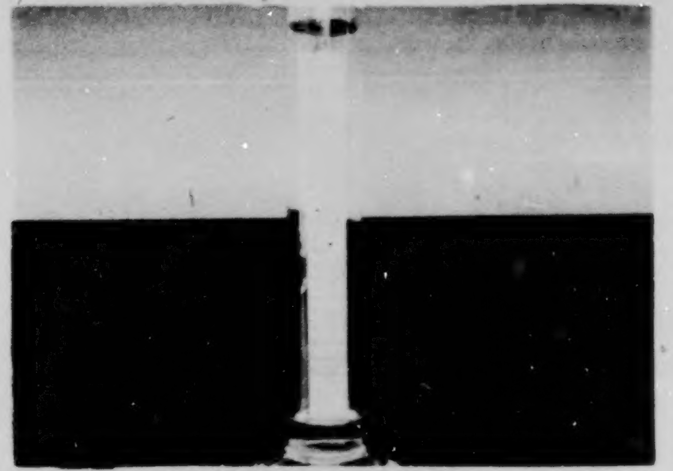


FIGURE 5-7

Leave the strip in the chamber until the front (top edge of the liquid as it moves up the strip) is at the 20 cm mark. Quickly remove the strip and use a pencil to mark the front. Hang the strip so it will dry. (Your instructor or someone he assigns may have to remove the strip if it takes longer than your class period.)

133

After the strip is dry, count the strip in the following manner: See FIGURE 5-8.

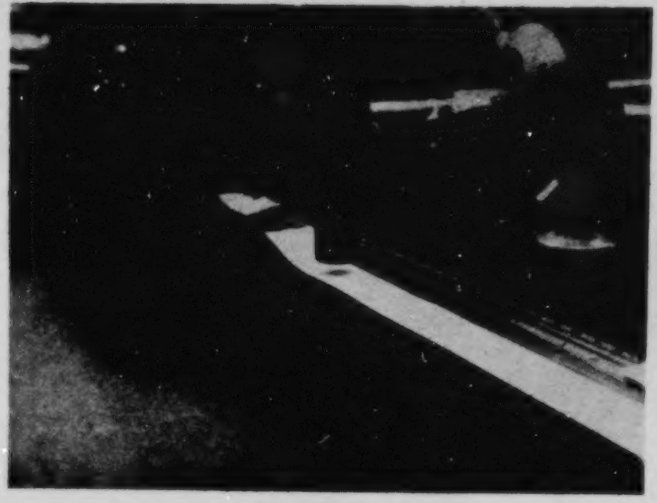


FIGURE 5-8

A. Tape a ruler or some other guide edge to the table.

B. Clamp your G-M tube so that it is about 0.5 cm above the table.

C. Cut a fine strip of tape about 0.5 cm long.

D. Center the tape on the side of the tube closest to you. (This will be used as a guide.)

E. Cut off the spot end of the chromatograph paper on a centimeter mark nearest the spot. Do not include any of the spot. Keep the spot end for later use.

F. Center the chromatograph strip under the G-M tube against the guide edge.

G. Line up your strip so that the tape center mark is lined up with the lowest numbered pencil mark on your chromatograph paper.

H. Take a two-minute count.

I. Move your chromatograph paper so that the next penciled centimeter mark is aligned with the center of the tube. Take another two-minute count.

J. Continue this process until you have taken counts at all of the lines marked on your paper.

K. Record your data in a table with headings:

Number on Chromatograph Paper	Two Minute Count	Adjusted Count	Adjusted Count with Paper Absorber

L. Study the data and subtract the lowest count from each of the two-minute counts. (This is called the adjusted count.) The lowest adjusted count should now be zero. Enter these values in your table.

M. On the high adjusted count readings, count again with a paper absorber between the G-M tube and the chromatograph strip. Use the same technique as you did previously. From each reading, subtract the same low count that you used previously and record.

N. Finally, count the zero line (original spot position) with and without the paper absorber and record.

Plot a graph with the position on the chromatograph paper on the horizontal axis and the adjusted two-minute count on the vertical axis.

Use a different color, and plot the adjusted counts with the absorber on the same graph.

Q1 - How many peaks do you find on your graph? Where are they located?

Q2 - Are any of the peaks due to alpha emission? If so, where are they located?

Q3 - Are any of the peaks due to beta and/or gamma emission? If so, where are they located?

Q4 - Mark the positions on your graph which represent the locations of the uranium-238 and thorium-234.

* * * * * * * * * * *

We have just separated two naturally occurring radioisotopes. Naturally occurring radioisotopes are, in general, the heavier elements (high atomic weights). What if we want a specific element (perhaps one with a low atomic weight) to be radioactive? What can be done? The first hint of an answer came from the studies of Irene Curie and her husband, Frederic Joliet. They studied the effect of alpha particles, from a naturally occurring radioisotope of polonium on certain light elements (boron, magnesium, and aluminum). For example, they found that if they bombarded aluminum with alpha particles, phosphorous and neutrons were produced. The reaction was:

Aluminum + alpha particles → phosphorous + neutron

or

$$^{27}_{13}\text{Al} + ^{4}_{2}\text{He} \longrightarrow ^{30}_{15}\text{P} + ^{1}_{0}\text{n}$$

The phosphorous-30 produced in this manner was not found in nature, and was radioactive. The problem with this technique is that both the aluminum nucleus and the alpha particle have a positive charge. Hence, most alpha particles bounce off or are deflected. Suppose one would accelerate (speed up) the alpha particle by using a special machine called an accelerator. The alpha particle in this case, is called a "projectile particle" because it is like a bullet fired from a gun. The projectile can be shot at the target nucleus (aluminum is our example). If the speed (energy) of the projectile particle is great enough to overcome the repelling force of the positively charged nucleus, the nuclei may then come close enough to interact with each other. This is called a nuclear reaction. As a result of a nuclear reaction different nuclei are often formed. Many man-made radioisotopes are produced in this manner. Two common types of accelerators, that you may have heard about, are linear accelerators and cyclotrons.

Another technique used to produce radioisotopes is the use of neutrons as bullets. This has the advantage that the bullets do not have an electrical charge, and, hence, will not need as much energy to interact with the target nuclei. In order to get the neutron bullets, we usually find a naturally occurring radioactive substance that emits neutrons as it decays. A large number of neutron reactions have been observed and many of them give rise to radioisotopes. An example of such a reaction is:

Uranium-238 + neutron ⟶ Uranium-239 + gamma radiation

or by using symbols:

$$^{238}_{92}U + {}^{1}_{0}n \longrightarrow {}^{239}_{92}U + \gamma$$

Another example: If a copper coin is exposed to neutrons, it may become radioactive. Why does this happen?

Copper + neutron ⟶ Radioactive copper

The copper atom formed is unstable, and a beta particle is ejected from the nucleus.

Radioactive copper ⟶ Zinc + beta particle

A problem exists. It seems that neutrons, in many cases, must be slow moving to interact with the target. Since the source will give off neutrons at various speeds, it is necessary to find some way to get the neutron to the desired speed for a particular reaction. In many instances the neutrons must be slowed down. It was discovered that elements with low atomic weights were better for slowing down neutrons than those with high atomic weights. A material which slows down neutrons is called a "moderator." An example is paraffin which contains lots of carbon and hydrogen atoms which have atomic weights of 1 and 12 respectively.

In order to see why the lighter material is a better moderator, consider the following sketch:

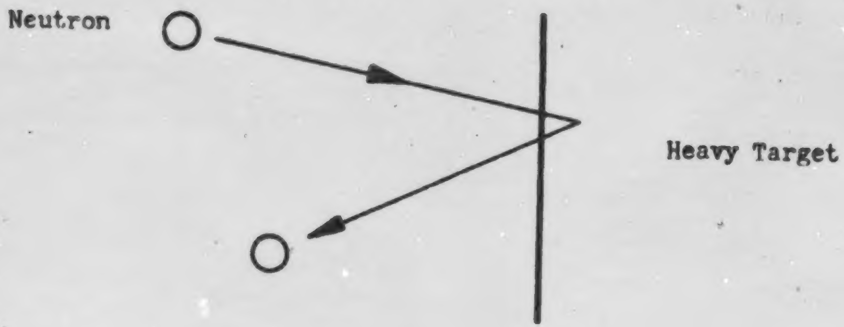


FIGURE 5-9

The neutron bounces off the target with practically the same speed that it had before collision. This is like a high speed marble striking a heavy bowling ball. The marble bounces off with practically the same speed and the bowling ball is scarcely affected. What would happen if we let our high speed marble hit another marble with a head-on collision? We would find that the "bullet" marble imparts all of its energy of motion to the "target" marble, which then moves forward with the same speed. See FIGURE 5-10.

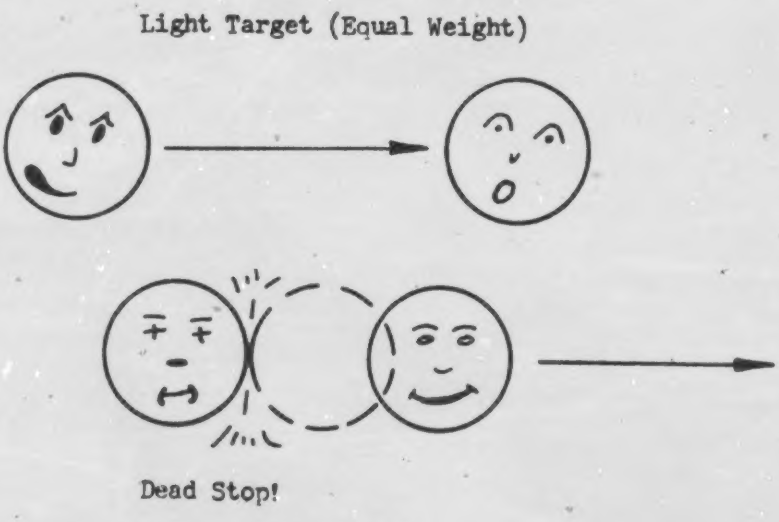


FIGURE 5-10-

If the target happened to be a hydrogen nucleus, the neutron would drive the nucleus (a proton) away from its original position in the paraffin. Of course, all collisions are not head on. In the majority of cases the impact is at an angle, which results in a sharing of energy. This results in a slower moving neutron.

Exercise 5-5:

a. Describe two ways by which an element can be made radioactive.

b. Could you use any of the techniques you learned thus far to detect neutrons?

c. If you had a source that you suspected was emitting neutrons, how could you use a detector to confirm or deny your suspicions?

NUCLEAR REACTORS: A SOURCE OF ENERGY

Einstein demonstrated mathematically that mass can be converted to energy.

$$\text{Energy} = \text{Mass} \times (\text{speed of light})^2$$

Experiments have verified this equation. A heavy atom like uranium-235 can break up into two smaller atoms. The neutrons and protons in the two smaller atoms do not weigh quite as much as the neutrons and protons in the uranium-235 atom. Some of the mass has been converted to energy. Neutrons make good atomic bullets because they are electrically neutral, and thus are not repelled by the positive charge of the target nucleus. If we fire a "slow" neutron at the uranium-235 nucleus, the neutron will enter the nucleus, break it into two smaller fragments, and energy will be released.

When a uranium-235 nucleus is split, more neutrons are released to become bullets for other nuclei. The splitting of atoms is called "fission." When this process continues, we have what is called a "chain reaction." See FIGURE 5-11.

A nuclear reactor is simply a device for starting and controlling a chain reaction. For reasons that will become evident, it could as well be called a "neutron machine."

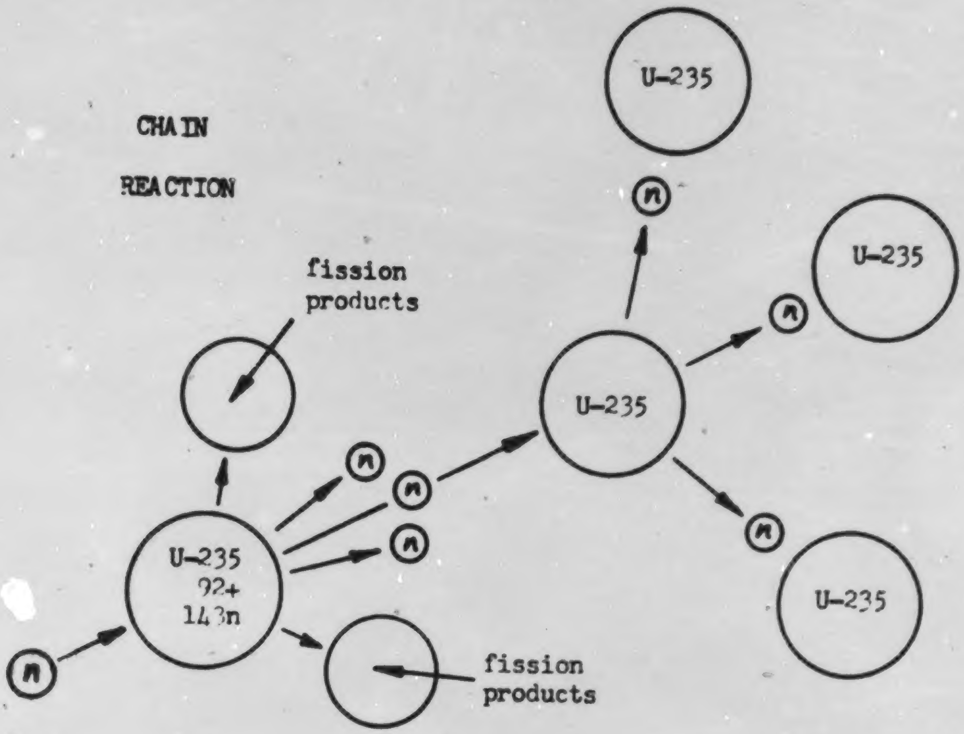

CHAIN
REACTION
U-235
n
U-235
fission products
n
U-235
n
n
n
n
U-235
92+
143n
n
U-235
fission products

FIGURE 5-11

Nuclear reactors are used in several ways:

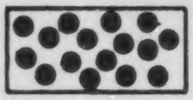
1. To supply intense fields or beams of neutrons for scientific experiments.
2. To produce new elements or materials by neutron irradiation.
3. To furnish heat for electric power generation, propulsion, industrial processes, or other applications.

Some of the atoms of uranium are spontaneously fissioning all the time. This makes it possible for a chain reaction to occur if a sufficient quantity of the material is assembled in the proper shape. The quantity of material necessary to produce a self-sustaining chain reaction is known as the critical mass of the material.

What happens as we assemble a critical mass piece by piece? See FIGURE 5-12.

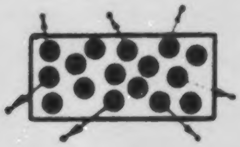
CRITICAL MASS CONCEPT

SKETCH A



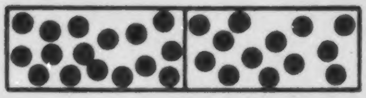
sub-critical mass of fissionable material

SKETCH B



more neutrons escape than are being produced

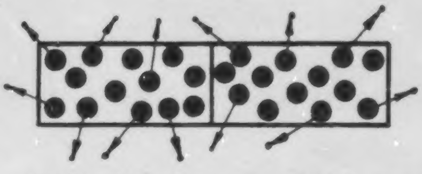
SKETCH C



additional sub-critical mass added

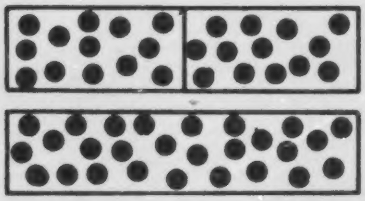
original sub-critical mass

SKETCH D



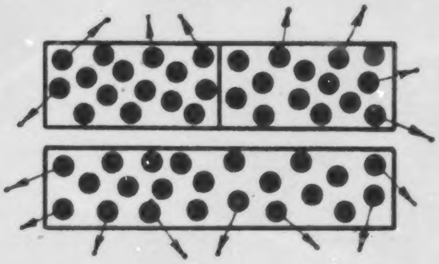
more neutrons are still escaping than are being produced

SKETCH E



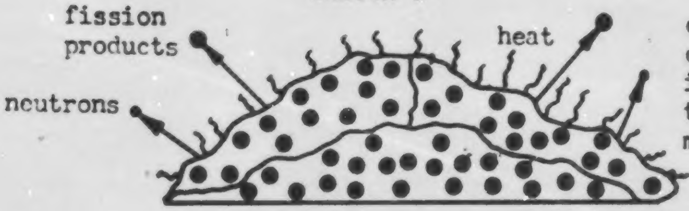
additional sub-critical mass added

SKETCH F



mass is now critical (more neutrons are being produced than are escaping)

SKETCH G



critical mass melts down thus changing the shape (surface area is increased causing more neutrons to escape than are being produced) mass then becomes sub-critical

FIGURE 5-12

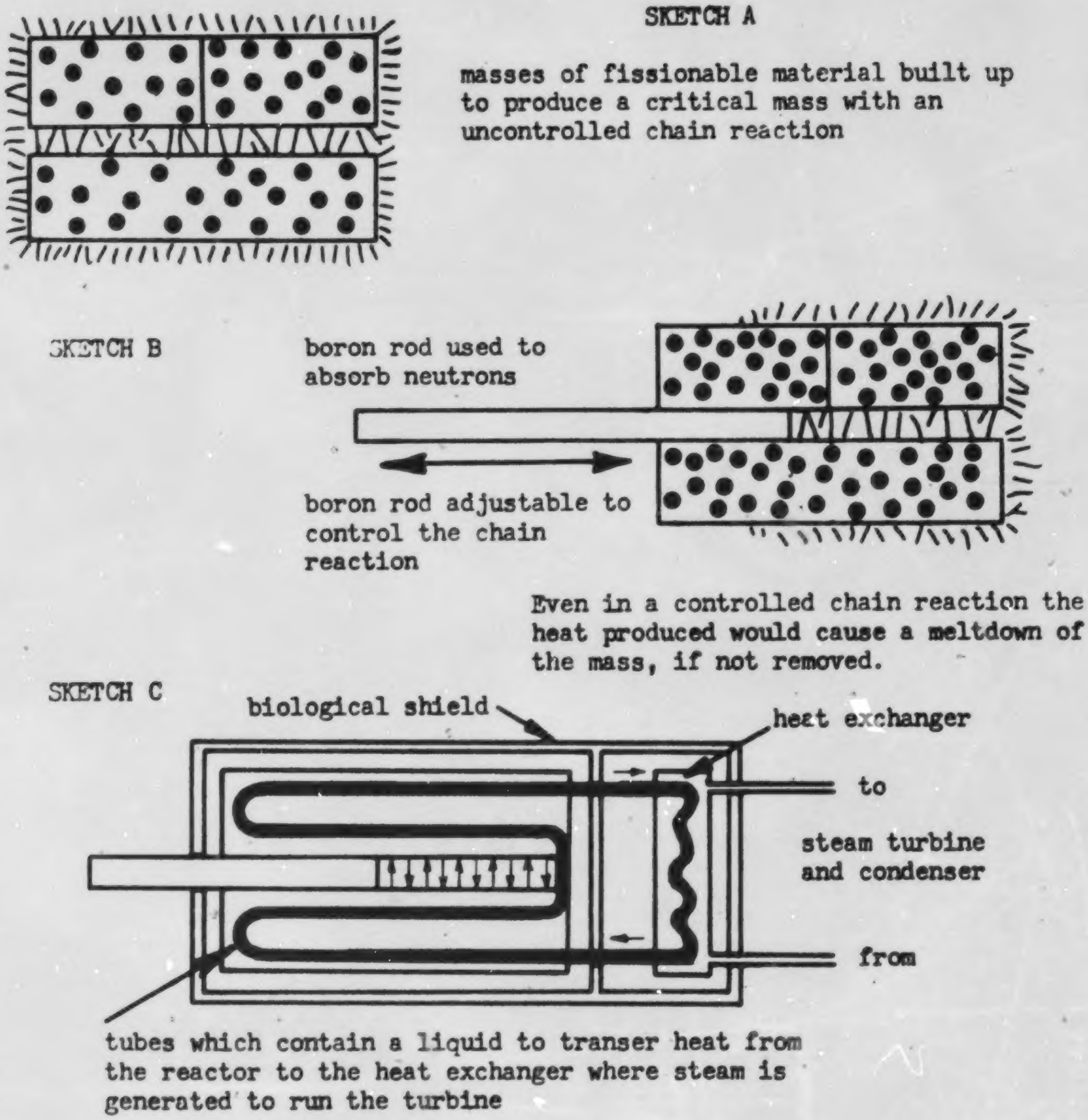
In "Sketch A" we see a piece of fissionable material. Each dot represents a uranium-235 nucleus (we are no longer concerned with electrons). In "Sketch B" we see what happens when one of the atoms spontaneously fissions and throws out neutrons which start the chain reaction. Even though uranium is a dense, heavy material, it is still mostly space. Because there is a relatively small amount of the material in proportion to the surface area, neutrons readily escape from the mass. As a result, the process does not multiply itself. "Sketch C" and "Sketch D" show what happens with the addition of another sub-critical mass. There is still a large surface area to mass ratio and neutrons can readily escape from the mass. There still is no self-sustaining chain reaction. This is because more neutrons are being lost than are needed to sustain the chain reaction. "Sketches E and F" show what happens when we add a third piece of fissionable material. Notice that the mass has been greatly increased without greatly increasing the surface area. As the chain reaction starts and the supply of neutron bullets begins to increase, as shown in "Sketch F," there is too little surface area for neutrons to escape before continuing the chain reaction. We now have a critical mass.

Because of the energy being released within the mass, it starts to heat up. As it heats, it eventually reaches its melting point. When it melts down, the surface area is increased, and the neutrons again escape in greater numbers than are needed to sustain the chain reaction. As a result, the chain reaction comes to a halt as shown in "Sketch G." This will all take place in an instant.

While this is going on, gamma rays are given off as well as neutrons. Both gamma rays and neutrons are extremely hazardous to people in the area. In addition, fission products are created in the process. They have a variety of half-lives and give off a variety of radiations. The heat generated by the reaction causes convection currents in the air. This spreads the fission products around the area. The result is an area highly contaminated with radioactive material.

This type of a reaction would not be useful. How can this be controlled to benefit man? FIGURE 5-13 shows the same pieces of fissionable material as shown in FIGURE 5-12.

ATOMIC REACTOR CONCEPT



SKETCH A

masses of fissionable material built up to produce a critical mass with an uncontrolled chain reaction

SKETCH B

boron rod used to absorb neutrons

boron rod adjustable to control the chain reaction

Even in a controlled chain reaction the heat produced would cause a meltdown of the mass, if not removed.

SKETCH C

tubes which contain a liquid to transer heat from the reactor to the heat exchanger where steam is generated to run the turbine

FIGURE 5-13

In this example, we have placed a boron rod between our two sub-critical masses. Boron absorbs neutrons much like a sponge soaks up water. Thus, when the rod is pushed between the two masses there is no appreciable interaction between the two sub-critical masses. We can control the reaction by pulling out the boron rod until we reach a point where we are allowing just enough neutron exchange to keep our chain reaction going. If we do this, a great deal of heat is generated and the mass could melt down as shown in "Sketch B." Thus, we must have some way to remove the heat. This is done by using a heat exchange medium such as water. Water, passing over the uranium, absorbs the heat generated by the fission reaction. The heat produced may be used to power a steam turbine and drive an electric generator. This is a nuclear power reactor. See "Sketch C." If something starts to go wrong with the reactor, it can be shut down by shoving the control rods in all the way.

The essential ingredient of reactor fuel is a fissionable material; a substance that readily breaks apart (or fissions) when struck by neutrons. The only naturally occurring substance fissionable by slow neutrons is uranium-235, an isotope of uranium constituting less than 1% of uranium found in nature. Almost all the rest of the natural element is uranium-238, which is called a "fertile material" because it can be converted into a fissionable substance, namely, plutonium. This occurs when uranium-238 is irradiated by neutrons.

Reactor fuel usually contains a mixture of fissionable and fertile materials. As the fuel is irradiated, in the course of reactor operation, atoms of the fissionable material are consumed. At the same time, new fissionable atoms are formed from the fertile material. With proper reactor design, it is possible to make more fissionable material than is being consumed. This is the basic idea in a "breeder reactor.."

In summary, the basic parts of a nuclear reactor are:

1. A core of fuel
2. A neutron moderator, which is a material that aids the fission process by slowing down neutrons
3. A means of regulating the number of free neutrons and thereby controlling the rate of fission
4. A coolant, which removes the heat generated in the core
5. Radiation shielding

Exercise 5-6:

a. Atom A emits radiation and forms a new element of nearly the same atomic weight. Atom B breaks into two smaller atoms. Both release energy and are radioactive. Which is a fissionable material, A or B? Are all radioactive substances fissionable?

b. Suggest a way that we might use a nuclear reactor to make a radioactive isotope.

c. In an atomic bomb, two sub-critical masses of fissionable material are brought together. If this forms a mass greater than critical, the chain reaction accelerates. The result is an explosion. How does a nuclear reactor differ from an atomic bomb? How are they alike? Why would the "melt down" process make it impossible for a nuclear reactor to explode?

FIGURE 5-14 shows us how we use a reactor to create radioactive isotopes and to change elements from one to another. For example, into a hole in the reactor we insert some cobalt metal. Cobalt, as found in nature, has 27 protons and 32 neutrons. When we push a rod of cobalt into the reactor, the atoms of cobalt are subjected to an intense bombardment of neutrons. Some of the cobalt atoms capture neutrons. These atoms are no longer cobalt-59, but cobalt-60. Cobalt-60 is radioactive; it gives off gamma and beta radiation and has a half-life of about 5.4 years. The cobalt was made radioactive by neutron capture.

NEUTRON CAPTURE

(HOW THINGS BECOME RADIOACTIVE)

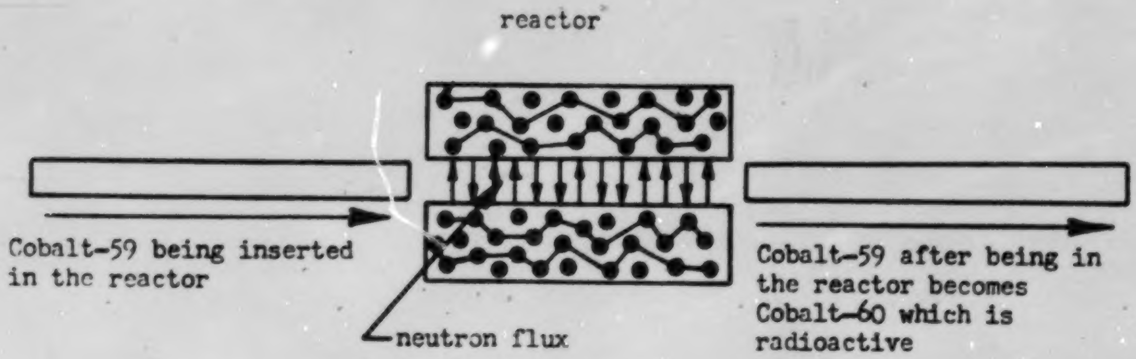

reactor
Cobalt-59 being inserted in the reactor
neutron flux
Cobalt-59 after being in the reactor becomes Cobalt-60 which is radioactive

FIGURE 5-14

Instead of cobalt, suppose mercury-200 is inserted into the reactor. Mercury-200 has 80 protons and 120 neutrons. In a reactor, a tiny fraction of the atoms of mercury capture neutrons. They now have 80 protons and 121 neutrons.

It so happens that mercury-201, when excited, throws out a proton, leaving 79 protons and 121 neutrons in the nucleus. This new element is gold. Thus we have made gold-200, a radioactive isotope of gold. This is shown in FIGURE 5-15.

TRANSMUTATION

(HOW AN ELEMENT IS CHANGED INTO A DIFFERENT ONE)

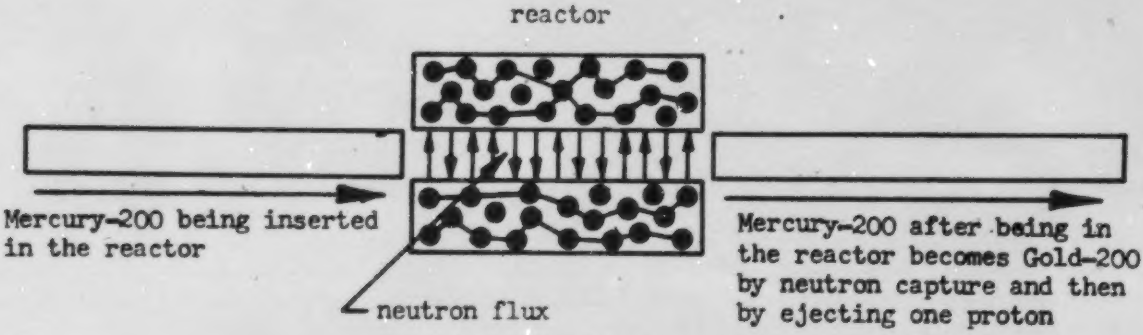

reactor
Mercury-200 being inserted in the reactor
neutron flux
Mercury-200 after being in the reactor becomes Gold-200 by neutron capture and then by ejecting one proton

FIGURE 5-15

In summary, we can get radioisotopes:

1. As fission products from the waste materials of an atomic reactor
2. By neutron capture in which the target material captures a neutron but is not changed to another substance.
3. By transmutation, that is, by the changing of one element to another, as we have seen in the case of the mercury.

Do the neutrons emitted in some nuclear reactions represent a hazard? Earlier in this chapter it was stated that protons are released when neutrons collide with hydrogen nuclei. This is the key to their dangers and detection.

Since all living things contain large quantities of hydrogen, neutron exposure can cause considerable proton production. The protons, in turn, can cause ionization and other damage to cells in tissues. This indicates the importance of personal protection from neutron bombardment.

Exercise 5-7:

If you were given a G-M tube detector and some paraffin, describe how you could arrange these materials to detect neutrons.

FUSION: A SOURCE OF ENERGY

The sun is a tremendous source of energy and has been producing this energy for an extremely long time.

How does it manage to do it? What is its source of energy?

It is known that the sun consists chiefly of hydrogen and that it has a temperature of about 40,000,000 degrees Fahrenheit near its center. It has been demonstrated that, at high temperatures, hydrogen nuclei fuse to form helium nuclei. The accompanying weight loss is converted into energy.

Hydrogen-2 + Hydrogen-2 ⟶ Helium-4 + energy

$$ {}^{2}_{1}H + {}^{2}_{1}H \longrightarrow {}^{4}_{2}He + \text{energy} $$

Since fusion of light weight nuclei is produced by extremely high temperatures,

147

fusion events are called "thermonuclear reactions."

The first large-scale application of thermonuclear energy was the hydrogen bomb, or "H-bomb." The high temperatures necessary for a fusion reaction were attained, for a brief time, by exploding a fission bomb (A-bomb). The temperature attained for this brief time is hot enough to cause some light nuclei to fuse. In the "H-bomb," light nuclei of deuterium (H-2) and/or tritium (H-3) are exposed to this temperature during such a fission explosion. The resulting fusion of these light nuclei cause the explosion to be hundreds of times more powerful than the fission device alone.

Fusion of light nuclei would be a much "cleaner" source of energy than fission because its "ashes" (helium) are not radioactive while the "ashes" of fission (fission products) are radioactive.

At present time, much time, effort, and money are being put forth to try to develop a technique to control this reaction.

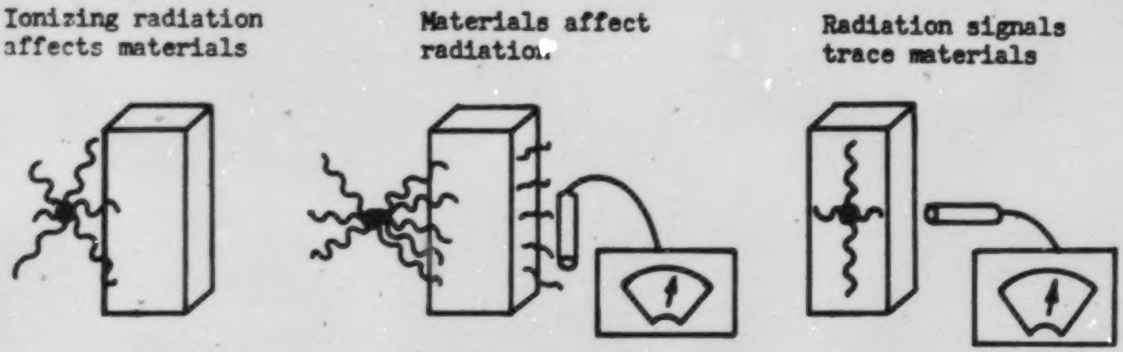
CHAPTER VI

VOCATIONAL OPPORTUNITIES IN NUCLEONICS

The first five chapters of the text have provided a basic understanding of nucleonics. Regarding nuclear radiation, you have learned some means of detection, some biological effects, personal protection, and a little theory. In the following chapters you will be looking at some of the applications of nuclear radiation.

The peaceful uses of atomic energy stagger the imagination. In industry, uses range from the detection of flaws in metal castings to the testing of laundry detergents. In applied biology or agriculture, it is used for such things as food preservation and the testing of fertilizers. Among the many medical uses are methods for locating tumors and determing blood volume.

The basis for using nuclear radiation is the fact that radioisotopes continually give off radiation. The uses of radiation that we shall explore are shown in FIGURE 6-1.



Ionizing radiation affects materials

Materials affect radiation

Radiation signals trace materials

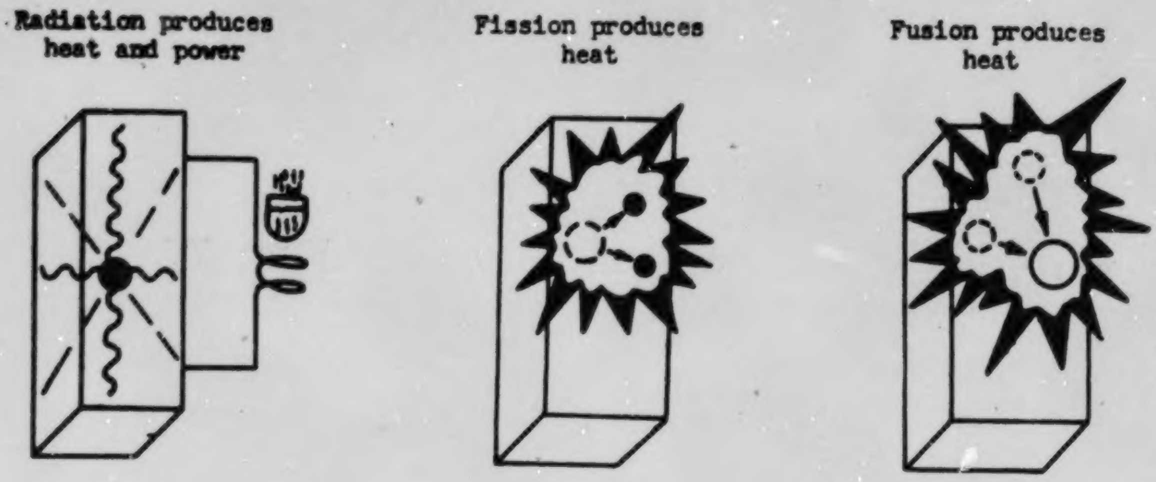
Pasteurization and sterilization
Static electricity elimination
Medical therapy
Radiation genetics
Polymerization
Chemical processes

Clinical Radiograph
Thickness and density gauging
Radiography
Level gauging

Metabolic studies
Flow measurement
Wear measurement
Leak detection

FIGURE 6-1

Other uses for nuclear radiation are shown in FIGURE 6-2.



Heat emission
Nuclear batteries
Thermoelectric devices

Electricity
Ships' fuel
Submarines' fuel

If controlled, could produce electricity

FIGURE 6-2

As industries investigate more and more of the limitless potential of nuclear radiation, they find it difficult to locate people trained in the handling of radioactive materials and the other aspects of nuclear technology.

So that you may study an area of your interest, the remainder of the book has been divided into three chapters: Industrial Application, Applied Biology, and Health Services.

The primary concern will be to acquaint you with the job opportunities for technicians in these areas. A technician is a person who directly or indirectly supports scientists and engineers in designing, developing, producing, or maintaining machines and materials. In general, these technician jobs are technical in nature but more limited in scope than those of the engineer or scientist and have a practical rather than theoretical orientation.

INDUSTRIAL APPLICATIONS

In this area there are many job titles which are usually unique to the particular industry. Many technicians have jobs that sometimes deal with radioactive materials. This section will acquaint you with some uses of nuclear radiation in industry.

One type of technician that is always employed by any industry that uses a great deal of nuclear radiation is the health physics technician (sometimes called the radiation protection man). His job is like a policeman's. He monitors work areas and makes sure that all employees follow safe procedures. In case of an accident, he will assist in the clean up under the direction of the health physicist. Many of the experiments and activities that you have performed to this point have acquainted you with some aspects of this job.

APPLIED BIOLOGY

There are many applications of nuclear radiation in this area. A few uses of nuclear radiation in applied biology are in the areas of agriculture, pharmaceuticals, food preservation, food production, insect control, and animal nutrition. As the number of uses for radioactive materials in applied biology increases, so does the need for trained technicians.

HEALTH SERVICES

The health services employ three basic types of technicians. One is called a radiologic technologist (X-ray technician). The technologist works with the guidance of a radiologist (a licensed doctor of medicine specializing in the use of X-ray and radioisotopes in the diagnosis and treatment of disease) or a roentgenologist (a licensed doctor of medicine specializing only in the use of X-ray in the diagnosis and treatment of disease). The radiologic technologist performs X-ray examinations on patients in various stages of health and disease. In small institutions and private offices, the radiologic technologist is expected to assist in treating patients with X-ray, as well as helping with clerical work involved in keeping records of X-ray examinations. The technologist may be responsible for developing the films.

Two specialty fields in radiologic technology have evolved; radiation therapy technology and nuclear medicine technology.

The radiation therapy technologist assists the radiologist in treatment of diseases by exposing affected areas of the patient's body to prescribed doses of X-ray or other forms of ionizing radiation. This new specialty requires that the technologist maintain proper operation of the controlling devices and equipment during treatment and be responsible for all treatment records.

The nuclear medicine technologist assists the physician in administering the required dose of radioisotopes given to patients to diagnose and treat disease. The technologist uses specialized equipment that traces and measures radioactivity within patients. These tracings aid the physician in making his diagnosis.

Two years of study are required for the radiologic technician. An additional year of study is required for either of the other technicians.

One technique which is used in all three areas just discussed is to use radioisotopes as tracers. This technique will be explored in the next experiment.

EXPERIMENT 6-1

TRACERS

INTRODUCTION:

How can we see inside something without taking it apart? Through the use of radioisotopes called tracers, one is able to discover the location, size, and position of objects. Without radioisotopes, this is sometimes a difficult or impossible task. In this experiment, we will consider what tracers do and hopefully develop an appreciation of how they are used in each of the three areas (industrial, applied biology and health services).

MATERIALS NEEDED:

G-M tube
Scaler or count rate meter
Tracer slab
Radioactive disc
Fish line

PROCEDURE & INTERPRETATIONS:

Tape the radioactive disc to the fish line so that it can be lowered into the tracer slab. See FIGURE 6-3.

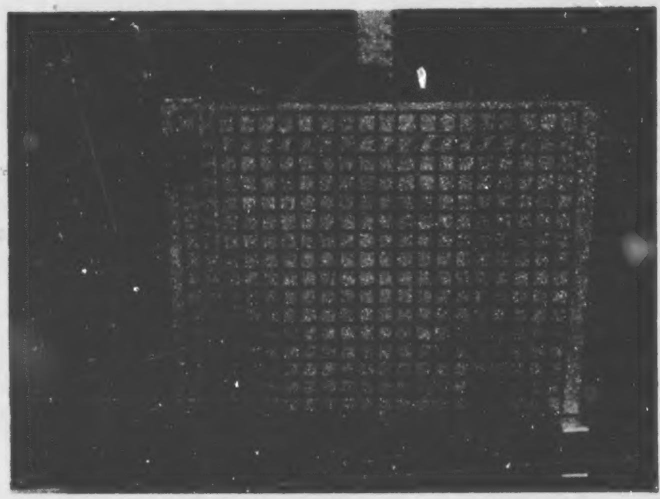


FIGURE 6-3

As the disc is lowered into the slab, it will randomly follow one of the four different paths. Lower the disc one half inch at a time and determine the location of the disc with the G-M tube. Record the location by stating the nearest intersection on the grid network, such as, K-4.

By locating the disc after each half inch displacement, you can find the path that the tracer (disc) follows through the slab. Draw a picture of the grid network and show the path that the tracer followed.

If time permits, repeat the procedure again.

Q1 - Suggest some uses of tracers in industry.

Q2 - Suggest some uses of tracers in applied biology.

Q3 - Suggest some uses of tracers in health services.

* * * * * * * * * *

The next three chapters explore applications of radioactive materials in industry. applied biology and health services. They are meant to be self pacing and, unless noted in the experiment introduction, need not be done in any particular order.

Unless otherwise directed by your instructor, you may begin with any experiment in any section.

If you are interested in the physical sciences or working with tools and machines, you might wish to begin in Chapter 7, which deals with industrial applications. If you are interested in applied biology, you should begin with Chapter 8. If you are interested in a career involving any of the health services, perhaps you should begin in Chapter 9.

As you work through these experiments, you should plan your time so you will be at a stopping point at the end of each period. You should also plan ahead so that any unusual materials you may need will be available.

CHAPTER VII

INDUSTRIAL APPLICATIONS

Past experiments have hinted at possible application of nuclear materials. In this chapter we would like to concentrate on industrial uses. It should be recognized that these uses are limited by the need for protection of workers. Thus, the amount of unshielded material used must be small and highly radioactive samples must be very heavily shielded.

Industry has been slow to develop widespread use of radiation, partly because development can be costly, and partly because workers prepared for this kind of work have not been availabe. The result has been frequent use of radioactivity by large corporations and much less by small companies. Hopefully this will change in the near future to the advantage of both small business and workers.

It is impossible to list, describe, and study all applications for several reasons. First, we haven't the time to study them all. Second, space prevents our listing them all. Finally, and probably most important, there are many applications yet to be discovered.

The following list indicates a few of the major industries already using radioactive materials and some of their applications.

INDUSTRY	USE
Tool	Gauging (thickness/density)
	Wear
	Flaw Detection (radiography)
Casting	Density Gauging
	Flaw Detection

Rolling Mill Paper/Sheet Metal	Continuous Thickness Monitor
	Continuous Thickness Control
	Quality Control
Plating	Gauging Thickness
	Quantity Deposit (radioactive deposit)
	Tracers
Fluid (gas/liquid) Supply/Storage	Volume Determination
	Depth Gauging (thickness)
	Liquid Level (sealed tank)
	"End of Run" Signal
Service (Plumbing)	Leak Detection (tracers)
	Flow Rate (tracers)
Production	"End of Run" Signal
Chemical	Detergent efficiency
	Tracers
Rubber	Tire Wear
Wood	Wear
	Tempering
Shipping	Power Production
Power and Light	Power Production

The experiments in this chapter are intended to demonstrate some of the industrial applications of radioactive materials. The practical forms may be more sophisticated than those used here, but the principles are the same.

You may proceed at an individual rate through this area.

EXPERIMENT 7-1

DENSITY GAUGING

INTRODUCTION:

Can radiation be used to gauge the density of a material? Can we find or detect large flaws in materials?

MATERIALS NEEDED:

Scaler
Gamma source
Timer
G-M tube
"Ingot" of variable density

PROCEDURE & INTERPRETATIONS:

Using a gamma source on one side of the "ingot" and a G-M tube on the other side, check the counts/minute in steps of 2 centimeters for the entire length of the "ingot". See FIGURE 7-1.

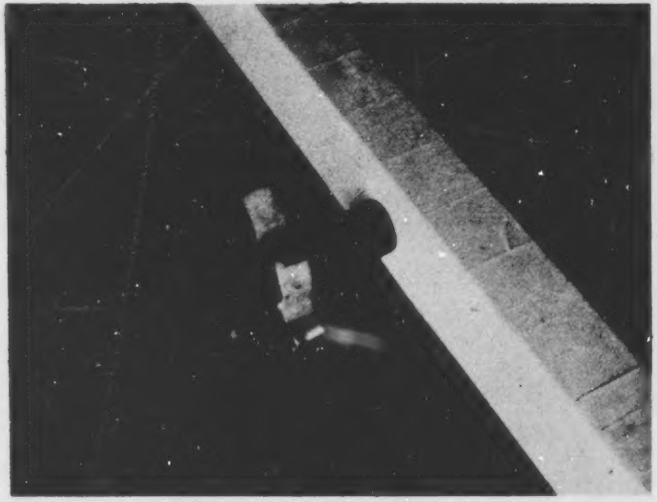


FIGURE 7-1

Prepare a data table. Plot a graph of counts/minute versus position along the "ingot".

Q1 - How could you account for the shape of your graph?

Q2 - How could the principle of this experiment be used to determine the water content of snow?

Q3 - In concrete, large stones and gravel are called aggregate. How could the principle of this experiment be used to demonstrate an even distribution of aggregate?

Q4 - How could the techniques of this lab be used to detect an air bubble in a solid casting?

For another technique for flaw detection, see Experiment 7-3.

EXPERIMENT 7-2

THICKNESS GAUGING

INTRODUCTION:

Can the thickness of a meterial be determine by the amount of radiation it will transmit?

MATERIALS NEEDED:

Scaler
10 Lead Shields
2 Cardboard sheets
Gamma Source
Timer
G-M tube
Centimeter ruler
Calibrated board

PROCEDURE & INTERPRETATIONS:

Stack ten lead sheets and measure their total thickness.

Q1 - What is the thickness of one sheet of lead?

Q2 - Why wasn't just one sheet measured rather than stacking ten and dividing?

The thickness you have just determined will be used for a graph later in the experiment.

FIGURE 7-2

Prepare the end-window G-M tube for counting gamma radiation. Then determine the background count.

Arrange the materials as shown in FIGURE 7-2.

With no shielding, except the two cardboard sheets, start the counter and adjust the distances so that several thousand counts/minute are being recorded. Do not change this spacing for the rest of the experiment.

Record several one minute readings and determine the average counts/minute. Be sure to correct for background. Now record the readings as successive sheets of lead are added until the count is reduced to less than one-half the original value. For maximum accuracy, make several one-minute counts for each thickness.

Plot the count rate vs. thickness on a sheet of regular graph paper. Have you drawn any other graphs which have this same general shape?

Try plotting the count rate vs. thickness on a piece of semi-log paper. Does this improve your ability to read the graph?

Q3 - What is the half-thickness of lead for this radiation?

Obtain an unknown from your instructor. The unknown will consist of lead sheets between two pieces of cardboard. Remove the original cardboard sheets making sure the gamma source and the G-M tube do not move.

Q4 - What purpose do you think was served by the original cardboard sheets?

Q5 - From the graph and the count taken on the unknown, what is the thickness of the lead sheets?

Q6 - Remove the lead from the cardboard packet. What is the thickness as measured with a ruler?

Q7 - By what percent do your two values for thickness differ?

$$\% \text{ difference} = \frac{\text{amount of difference}}{\text{thickness measure by ruler}} \times 100\%$$

Q8 - How can the principle of this experiment be used in industry?

Q9 - Does this method require gamma radiation, or could beta be used? What qualifications would be needed?

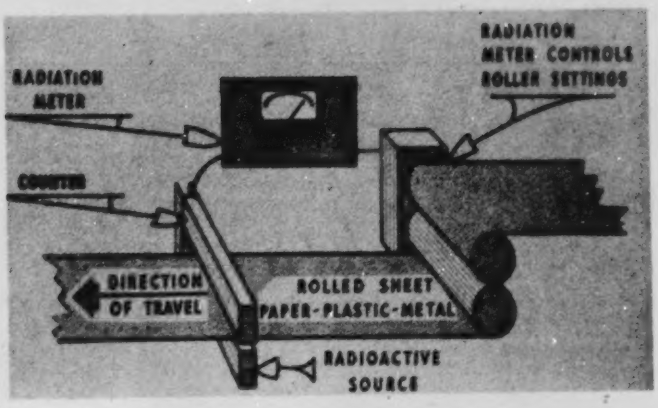

RADIATION METER CONTROLS ROLLER SETTINGS
RADIATION METER
COUNTER
DIRECTION OF TRAVEL
ROLLED SHEET PAPER-PLASTIC-METAL
RADIOACTIVE SOURCE

FIGURE 7-3

FIGURE 7-3 shows an application of radioactive gauging in industry. Conventional gauging methods involve physical contact between the measuring instrument and the material being measured.

Q10 - What advantages can you see in the radioactive gauging method?

EXPERIMENT 7-3

FLAW DETECTION

INTRODUCTION:

Industrial needs take many forms. Suppose we had a casting with an air buble trapped inside. This could weaken the casting. The result could be dangerous if the flaw were not detected. How can such a flaw be detected without cutting into the casting?

MATERIALS NEEDED:

Gammator
1 piece X-ray film 2" x 2½ (to be made up by instructor)
Developer and fixer for X-ray film
Objects to be "X-rayed?
Kodak Velox print paper 2½ x 3½ (F-3 or F-4)
Developer and fixer for print paper
Dark room

PROCEDURE & INTERPRETATIONS:

Tape the packet of X-ray film to the object to be "X-rayed". Place the object and film in the Gammator chamber such that the film is behind the object as you look at it. Do not have the Gammator turntable rotating. Expose the object and film to the gamma source in Gammator for 2 or 3 seconds. Develop the film using the techniques of Experiment 2-1.

Q1 - After the film has been developed, do you see any image on the film?

Q2 - Since this is a film negative, what can you say about the exposure?

Q3 - In Experiment 2-1, you exposed the film for 24 hours using small solid sources. In this experiment you overexposed the film in just 2 or 3 seconds. What does this tell you about the source in the Gammator?

If the film was overexposed, there are three possible remedies: 1) reduce the activity of the source, 2) reduce the exposure time, or 3) use a less sensitive film. The source activity in the Gammator cannot be reduced very easily. The time of exposure, at two seconds, is also difficult to shorten. Thus, the easiest way to control exposure would be to use less sensitive film.

Repeat the experiment using print paper, "X-raying" each of the objects with an exposure time of about 5 minutes. Develop the print paper using a dark room or other dark place.

Q4 - How do the pieces of print paper compare?

Dark areas on the film indicate areas where there are flaws or holes in the object.

Q5 - If this is the case, which of the objects is flawless?

Q6 - If flaws were present in any of the objects, describe or sketch their shape.

For another technique for flaw detection see Experiment 7-1.

EXPERIMENT 7-4

STRAIN GAUGES

INTRODUCTION:

Strain may be defined as the change of length of a material divided by the original length, where a stretching force is applied. How can radioactivity be used to measure strain?

MATERIALS NEEDED:

Radioactive source (beta)
3 Ringstands
2 Buret clamps
G-M tube and counting equipment
Rubber sheet 20 cm x 4 cm
Weight hanger and weights
Support rod for rubber sheet
Centimeter ruler

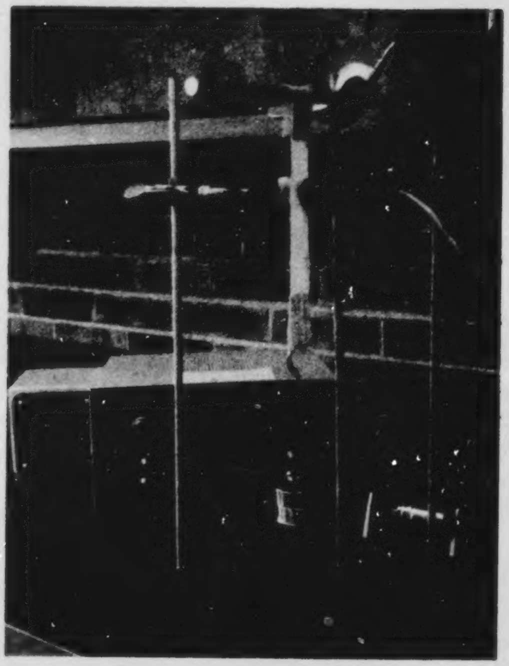


FIGURE 7-4

164

PROCEDURE & INTERPRETATIONS:

Loop the rubber sheet over the support rod and staple securely. Staple a loop in the other end of the rubber sheet to hold the weight hanger. Clamp the G-M tube to a firm support on one side of and near the center of the rubber sheet with the window toward the sheet. Record the background count. Clamp the beta source directly opposite the G-M tube. See FIGURE 7-4.

Determine the activity with no weight on the hanger and record. Measure the length of the rubber sheet between the support rod and the weight hanger. Add weights, take counts, and measure lengths to complete a data table similar to FIGURE 7-5.

Weight including hanger (gms.)	Length L (cm)	Change in length ΔL (cm)	Strain S	Counts/ minute	Corrected Counts/ minute
200					
400					
600					
800					
1000					

FIGURE 7-5

Strain may be computed using the following formula:

$S = \frac{\Delta L}{L}$ where S = Strain

ΔL = Change in length (measured length minus original length)

L = Length

Plot a graph of activity versus strain.

Q1 - Why does the count change as weight is added?

Q2 - How could the strain on the drive belt on FIGURE 7-6 be determined for several speeds and load conditions?

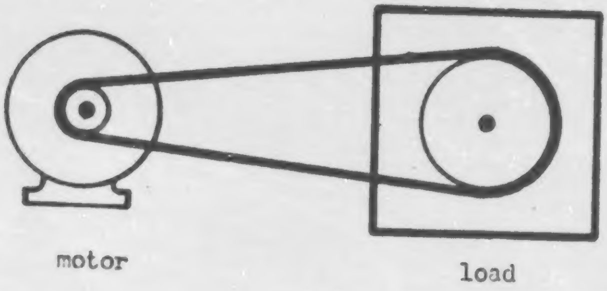


FIGURE 7-6

EXPERIMENT 7-5

WEAR DETERMINATION

INTRODUCTION:

Industry is concerned about the life expectancy of equipment and ways of extending this life expectancy. To assist in this goal, methods of wear determination and reduction are needed. Can the use of radioactive materials help in this regard? Can we provide the means for wear study? For instance, can we determine how much more wear there is on a piece of wood when rubbed with a piece of sandpaper than with a piece of cardboard? With a piece of cloth?

MATERIALS NEEDED:

G-M tube and counting equipment
Wooden block
Sandpaper
Cloth
Cardboard
Weight (1 kg)
Heat lamp
Minigenerator Sr90/Y90
Safety tray and liner
Plastic gloves

PROCEDURE & INTERPRETATIONS:

Elute 3 ml from the minigenerator into a small beaker. Pour the eluted indium over the block of wood. Thoroughly dry with a heat lamp. Record the background count of the sandpaper, cloth, and cardboard. With the 1 kg weight resting on the block of wood, pull it across the cardboard, cloth, and then sandpaper several times. Be sure this is done the same number of times and over the same section of each sheet. See FIGURE 7-7.

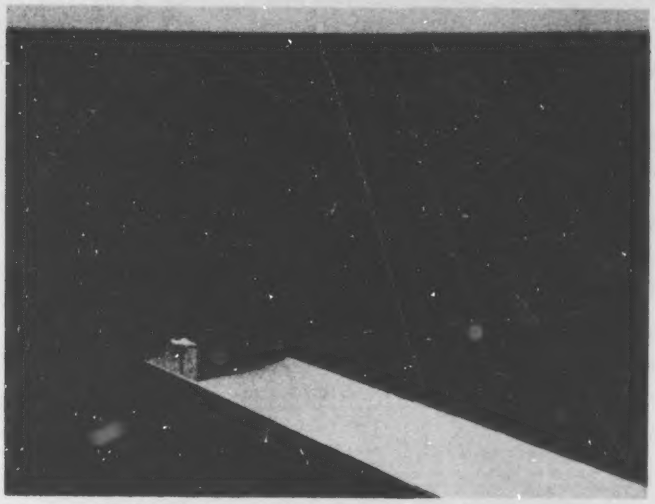


FIGURE 7-7

Record the count at the center of each sheet after the wear process is completed. Also record the corrected count.

Q1 - Which sheet showed the greatest increase in activity?

Q2 - Which sheet showed the least increase in activity?

Q3 - What is the ratio of wear caused by the sandpaper to that caused by the cardboard?

Q4 - What is the ratio of wear caused by the cardboard to that caused by the cloth?

Q5 - Suppose a technician is testing methods of hardening drill bits. How could he use this technique?

Q6 - Suppose a technician is testing the wear prevention ability of engine oils. How could he use this technique?

EXPERIMENT 7-6

DETERGENT EFFICIENCY

INTRODUCTION:

Can radioactive materials be used to investigate the abilities of commercial products? Specifically, can they give an indication of the cleansing ability of detergent?

MATERIALS NEEDED:

G-M tube
Scaler
Heat lamp
Timer
Lamp black
Motor oil
100 ml beaker
Phosphorous 32 solution
4 different powdered detergents
4 1" squares of cotton cloth
Forceps
Wood splints
4 watch glasses
4 small bottles with screw caps
Safety tray
Plastic gloves

PROCEDURE & INTERPRETATIONS:

Place one gram of lamp black in a beaker. Add 1 microcurie of Phosphorous 32 and mix thoroughly using a glass stirring rod. Allow the mixture to dry. Use a heat lamp to dry the mixture more quickly.

To dry mixture add 5 ml of motor oil and mix well. Spread the mixture on the pieces of cloth. Make the smears the same size on each cloth square. Place the pieces of cloth on separate watch glasses and check the count on each.

Label the bottles to indicate the detergent brand to be used in each. Place 0.5 grams of detergent in each bottle as marked. Place a cloth sample in each bottle, fill it half full of water, and cap it tightly. Shake each bottle for about 2 minutes.

Remove the cloths, place them on clean watch glasses and allow to dry. Pour the wash liquids into the "hot" sink and rinse the glassware.

When the cloth samples are dry, find the activity of each. Complete a data table with the following headings: Detergent Brand, Count for Unwashed Cloth, and Count for Washed Cloth.

Q1 - Was the change in the count the same for each detergent?

Q2 - Was one obviously better than the others?

Q3 - Was one obviously poorer than the others?

Bear in mind that one investigation of this kind is not conclusive. The experiment would have to be repeated many times to give a true indication.

Q4 - What particular ingredient was cleansed from the cloth?

EXPERIMENT 7-7

FLOW RATE OF FLUIDS

INTRODUCTION:

How can we determine how fast a liquid or gas is moving? Can we prove that the liquid moves in certain paths? Can we demonstrate that a prescribed volume of liquid has passed a particular point in a closed system?

MATERIALS NEEDED:

2½ meters of small diameter tubing
Scaler or count rate meter
G-M tube
T-joint
Plastic squeeze bottle
Minigenerator Cs 137/Ba 137m
Beaker (250 ml)
Graduated cylinder (50 ml)
Stopwatch
Centimeter ruler

PROCEDURE & INTERPRETATIONS:

Arrange the materials for this experiment as shown in FIGURE 7-8. To a plastic squeeze bottle add 5 to 10 drops of Ba 137M from the minigenerator. Dilute with an equal volume of water. This is your radioisotope.

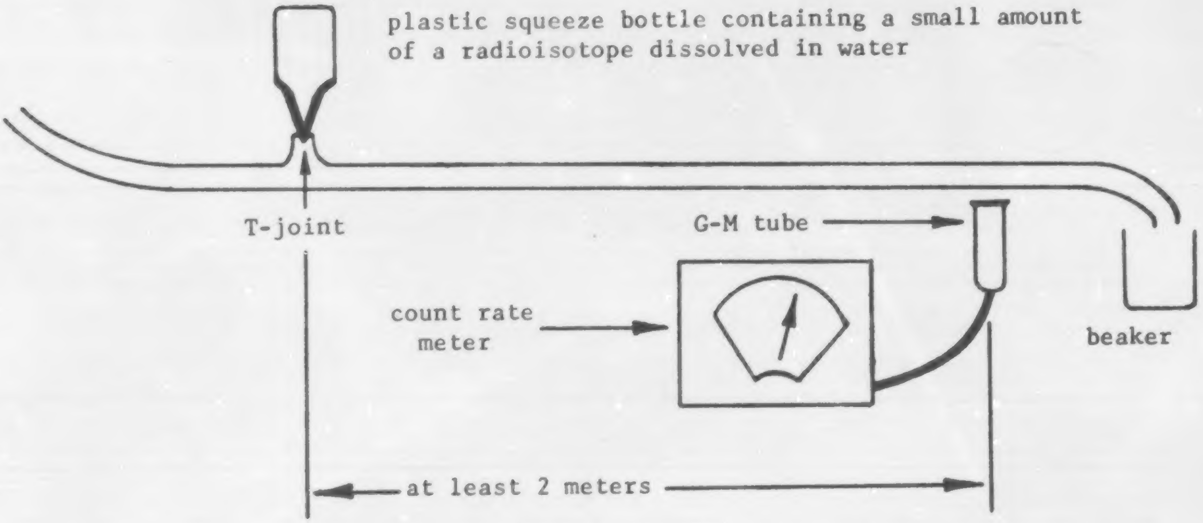

plastic squeeze bottle containing a small amount of a radioisotope dissolved in water
T-joint
G-M tube
count rate meter
beaker
at least 2 meters

FIGURE 7-8

Measure the inside diameter of the small diameter tubing.

Q1 - What is the volume of the tube between the T-joint and the detector? Hint: Think of it as a long skinny cylinder. $V = \pi r^2 h$ (where r is the inside diameter divided by 2 and h is the length of the tubing between T-joint and detector).

Allow the counter or count rate meter to warm up. Adjust the water flow to a very slow but steady rate (the slower the better). Inject the radioisotope, start the stopwatch and move the beaker under the hose end at the same time. Watch the scaler or count rate meter. When the scaler indicates the highest rate of count, stop the stopwatch and move the beaker from under the tubing simultaneously. (Do not turn the water off.)

Q2 - Calculate how much water should have run into the beaker during the time the stopwatch was running. Check this by pouring the water from the beaker into a graduated cylinder. A further check on your prediction can be made by allowing water to run into a graduated cylinder for the same length of time as it took for the radioactivity to flow from the point of injection to the detector.

Q3 - Do the three measures of volume seem to agree?

Q4 - What are the major sources of error in this experiment? (Be sure to indicate the source for two methods.)

Q5 - How might the pipeline industry use the principles involved in this experiment? (Assume that one pipeline is used by 4 gasoline companies.)

EXPERIMENT 7-8

DETERMINATION OF THE LIQUID VOLUME IN A CONTAINER

INTRODUCTION:

Suppose we wish to determine the volume of oil in an underground tank. How could radioisotopes help in this determination?

MATERIALS NEEDED:

Scaler
G-M tube
Small vial
Stirring rod
Syringe and needle
Graduated cylinder (50 ml)
Minigenerator Sn 113/In 113
Unknown sample

PROCEDURE & INTERPRETATIONS:

Determine and record the background radiation. Calibrate a vial by adding 2 ml of water and marking the water level on the vial, add 2 ml more and mark the 4 ml level on the vial. Discard the water. Elute 10 drops from the minigenerator into the vial and fill to the 2 ml mark with water. Place the vial next to the G-M tube as shown in FIGURE 7-9.

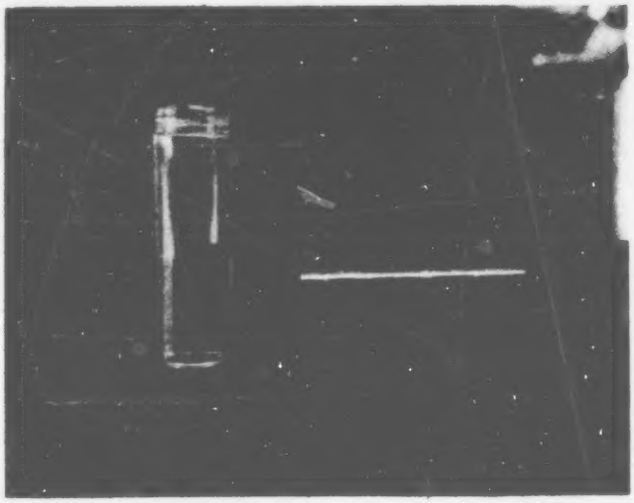


FIGURE 7-9

Take several counts and determine the corrected count on the solution. Add 2.0 ml of water to the vial and its contents. Mix thoroughly. Remove 2.0 ml of the solution using a syringe and needle. Only 2.0 ml of solution should remain in the vial.

Q1 - How much of the original radioisotope remains in the vial?

Q2 - What corrected count would you expect if you checked this sample?

Measure the count to check your prediction.

If you felt that the activity should vary according to the concentration of the radioisotope, then perhaps the following proportion could be used to calculate the unknown volume:

$$\frac{V_1}{V_2} = \frac{A_2}{A_1}$$

Where: V_1 = original volume of radioisotope solution (in this case 2 ml)

V_2 = total volume of the diluted solution (in this case 4 ml)

A_1 = activity of the original radioisotope sample

A_2 = activity of the diluted solution

This inverse proportion says, in effect, that doubling the volume by dilution halves the activity. Tripling the volume will cut the activity to 1/3.

Q3 - Does the proportion work for the samples just measured?

Obtain a container of liquid from your instructor. Withdraw 1 ml of liquid from the "unknown" container and place it in your empty marked vial. Elute the minigenerator into the vial to bring the volume up to the 2 ml mark. Mix thoroughly and take several counts as before. Pour the contents of the vial into the "unknown". Mix thoroughly. Withdraw 2 ml from the unknown and place it in your marked vial. Take several counts. Calculate the volume of the "unknown". (Remember: you added one ml liquid in the form of an isotope.) After recording your result, make a direct measurement of the volume using a graduated cylinder.

Q4 - How close was your prediction?

Suppose that one liter of a radioisotope-tagged compound (soluble in oil) with an activity of 50,000 cpm is added to an oil tank as mentioned in the start of this experiment. After agitation within the tank, a liter of oil is withdrawn and its activity is found to be 250 cpm.

Q5 - What is the volume of the oil in the tank?

Suppose it is very important for a doctor to determine the volume of blood in a patient's body.

Q6 - How could the methods of this experiment be used to solve the doctor's problem?

EXPERIMENT 7-9

LIQUID LEVEL

INTRODUCTION:

If the shape and size of a container is known, the liquid level can be calculated once the liquid volume is known. Is it possible to determine the liquid level more directly?

MATERIALS NEEDED:

G-M tube and counting equipment
150 ml beaker
Radioactive source (Gamma - .5 μc Cesium 137)
Sealed tube - contents not exposed

PROCEDURE & INTERPRETATIONS:

PART I:

Place the gamma source under the beaker and mount the G-M tube on a ring-stand over the beaker. The window of the tube should be about even with the top of the beaker and facing down. See FIGURE 7-10.

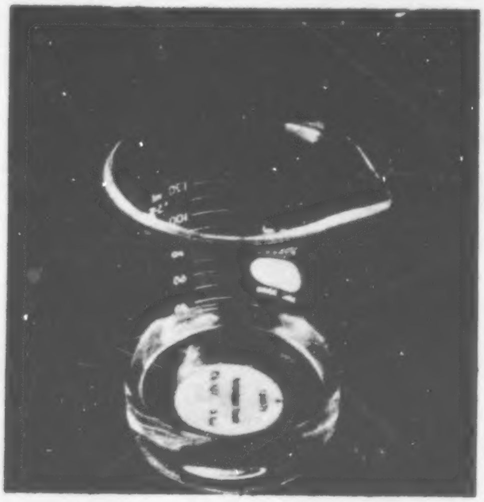


FIGURE 7-10

Take count per minute readings for various depths of water and complete a data table similar to FIGURE 7-11.

Water Depth (Centimeters)	Counts/Minutes	Corrected Counts/Minutes
0		
.5		
1		
1.5		
2		
2.5		
3		
3.5		
4		

FIGURE 7-11

Plot a graph of water depth versus counts per minute.

Q1 - What would the count/minute reading be if the water depth were 3.8 cm?

Q2 - What would the count/minute reading be if the water depth were 6 cm?

Q3 - What other information would be needed to determine the volume of the liquid in the container?

Q4 - Could the graph prepared in this experiment be used to determine the depth of a brine solution? Explain.

PART II:

Suppose a highly toxic or corrosive liquid must be stored in a sealed container. Can we measure the depth of the liquid using radioactive materials?

Obtain an "unknown" from your instructor and devise a method to determine its liquid level. Notice that the method used in Part I is difficult to apply here.

Q5 - Describe the method you devised for level determination.

Q6 - Describe how your method might be used in industry.

Q7 - Describe the advantages or disadvantages of your method as compared with the method of Part I.

EXPERIMENT 7-10

POLYMERIZATION

INTRODUCTION:

Can radiation produce polymerization? (Linking of small molecules to form large molecules.) One evidence of polymerization is the changing of a liquid to a solid. Perhaps industry can use this effect to change the properties of some existing materials.

MATERIALS NEEDED:

Gammator
Methyl methacrylate
5 glass vials with plastic caps
5 watch glasses
Acetone

PROCEDURE & INTERPRETATIONS:

Wash the glass vials with a few drops of acetone. Half fill the vials with methyl methacrylate and securely cap. Irradiate the vials and their contents according to FIGURE 7-12. (Refer to Experiment 2-4 to calculate the dose in roentgens).

VIAL #	IRRADIATION TIME (hrs.)	DOSE IN ROENTGENS	RESULT
1	0		
2	6		
3	24		
4	30		
5	48		

FIGURE 7-12

After the vials have been irradiated for the prescribed period of time, pour the liquid contents of each vial onto separate watch glasses. Put the vials and watch glasses in a well ventilated location (preferably under a hood) and allow the liquid to evaporate.

When the evaporation is complete, carefully break the glass vial away from any remaining contents. (Wrap in toweling before breaking.)

Q1 - Is there a solid on any watch glass after evaporation? If so, which one(s)?

Q2 - Is there a solid in any vial after evaporation? If so, which one(s)?

Q3 - How did the amount of radiation affect the quantity of solid formed?

Q4 - Within what irradiation range was a solid formed?

Q5 - What evidence is there to indicate that the solid resulted from radiation and not evaporation?

EXPERIMENT 7-11

PLASTICIZING WOOD

INTRODUCTION:

(NOTE: If you have not done Experiment 7-10, be sure to do so before starting this experiment.) In the last experiment, we saw how a liquid can become a solid by irradiation. This is an interesting result, but does it have a practical application?

MATERIALS NEEDED:

Gammator
Methyl methacrylate
4 wood samples (2 soft & 2 hard) about 1 cm^3
Plastic bag
Aluminum foil
Fine sandpaper
Filtering flask
Separatory funnel
1 hole rubber stopper to fit filtering flask and separatory funnel
Test tube to fit inside filtering flask
Aspirator
Vacuum hose
Heat lamp or drying oven
Ringstand and buret clamp
Weight to fit inside test tube
Screw type hose clamp

PROCEDURE & INTERPRETATIONS:

Dry the wood samples in an oven or under a heat lamp for about one hour. While waiting for the wood samples to dry, arrange the materials as shown in FIGURE 7-13. (Note the test tube inside the filtering flask.)

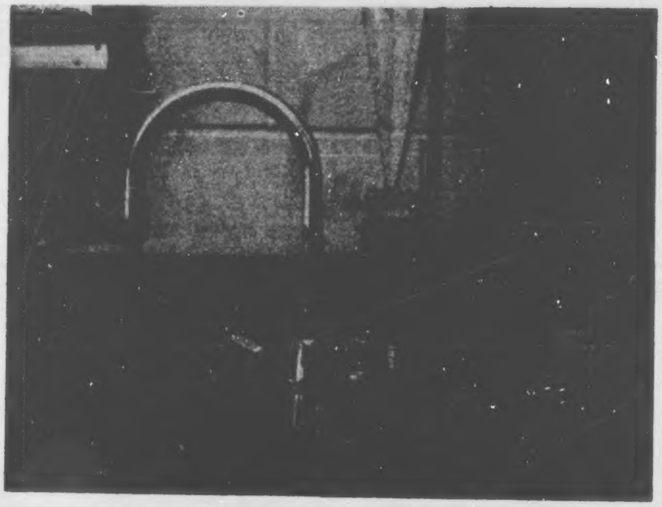


FIGURE 7-13

After the wood samples are dried, remove the test tube from the filtering flask and place two of the wood samples (one hard and one soft) in the test tube. Put the weight on top of the wood samples. Set the other two blocks aside to be used as controls.

Reassemble the vacuum system, placing the test tube and contents inside the filtering flask. With the separatory funnel's valve closed, add about 50 ml of methyl methacrylate. Now draw a vacuum on the system by letting water run through the aspirator at full speed for about 5 minutes.

Tighten the screw clamp to close the vacuum line. Turn off the aspirator. Open the separatory funnel's valve and allow the methyl methacrylate to flow over the wood blocks. Close the separatory funnel's valve when the blocks are covered. Disconnect the vacuum hose from the aspirator. Open the screw clamp and allow air to enter the flask. Reclose the screw clamp immediately. Allow the samples to remain immersed for at least 15 minutes. (Overnight is acceptable.)

Pour off the excess liquid, remove the samples from the test tube, and place them on aluminum foil. Quickly wrap the samples in the foil and place the combination in a plastic bag. Secure it with rubber bands. Irradiate the wrapped sample in the Gammator for 30 or more hours.

After the required exposure, remove the sample from the Gammator, unwrap and evaporate until thoroughly dry. Safety Note: AVOID FUMES AND CONTACT WITH SKIN AND EYES. Pair the two softwood samples and the two hardwood samples. Split the irradiated and the control softwood samples. Answer the following questions by observing the freshly split surfaces.

Q1 - Rub the treated and untreated pieces of wood with sandpaper. How is the effect of the sandpaper different on the two blocks?

Q2 - Which of the two blocks would be polishable?

Q3 - Which block has the greater mechanical strength?

Q4 - Which is harder and more scratch resistant?

Split the two hardwood samples (irradiated and control). Answer Q1, Q2, Q3, and Q4 for these samples.

Q5 - Did the liquid seem to completely penetrate the wood samples?

Q6 - What was the purpose of the vacuum system?

Q7 - Suggest a practical application of this process.

EXPERIMENT 7-12

ATMOSPHERIC CONTAMINATION

INTRODUCTION:

In Chapter 2 we observed the dust collected from the atmosphere and found it to be radioactive. The problem an ecologist faces in such an observation is identifying the radioactive substance. If it can be identified, perhaps its source can be found. Can we identify the collected material or at least eliminate many materials from a long list?

MATERIALS NEEDED:

G-M tube
Scaler
High volume air sampler or tank type vacuum cleaner
3 x 3 wire screen
Filter paper
Ringstand and buret clamp

PROCEDURE & INTERPRETATIONS:

Place a piece of clean filter paper on the work surface. Clamp the G-M tube, connected to a scaler, onto a ringstand with a buret clamp. Position the G-M tube about .5 cm above the filter paper and take a count.

Place a piece of wire screen over the intake of a tank type vacuum cleaner. (Wire screen is not needed if a high volume air sampler is used.) Position a piece of filter paper over the screen so that air will be drawn through it. Place the air sampler or vacuum cleaner on the school roof or grounds. Operate for about 1 hour. Record the wind direction. Place the dirty filter paper, as before, .5 cm from the G-M tube.

Take a one minute count every other minute for 30 minutes. (Refer to Experiment 4-1 for procedure.) Arrange the data in three columns for time, counts/minute, and corrected counts/minute.

You will now use the procedures of Experiment 4-1 to determine the half-life of your sample. Using semi-log graph paper, plot the corrected counts/minute on the vertical axis and time on the horizontal axis.

Q1 - What is the half-life of the substance on the dirty filter paper?

Q2 - Refer to Appendix D. Could the substance be uranium 238, strontium 90, or carbon 14? Explain your answer.

Q3 - Could the substance be barium 137? Explain.

Q4 - Which of the Appendix D materials could it be?

To determine the source of the radioactive substance, it would be necessary to do the experiment several times, particularly with the wind from several different directions.

CHAPTER VIII

APPLIED BIOLOGY

In this chapter we will, in general, concentrate on the application of the ideas of Chapters 1 through 5 to biology. The amount of radioactivity the biologist uses varies widely, depending upon what he wishes to accomplish. Biologists interested in tracing the movement of chemicals or growth acceleration use small quantities of radioactive material. Others, interested in destructive effects or mutations use larger quantities.

The use of radioactive materials has, for the most part, been reserved for research. This has changed in recent years to include applications. This, in turn, has been limited by the number of people prepared to work in this field.

The complete list of applications would be quite long and is growing daily. As new technicians are acquired, the applications will expand and be limited only by the imagination of the scientists and technicians.

The following list indicates a few of the major fields and the purpose of each application.

FIELD	PURPOSE
Animal Health	Disease study (blood circulation and analysis)
	Insect control
Animal Growth (Meat Production)	Rate of assimilation of vitamins and minerals (Chemical uptake and diffusion)
Weed Control	Rate of uptake of chemicals and diffusion
Plant and Animal History	Radioactive dating
Plant Growth	Methods of improving % germination (yield/acre)
	Low dose irradiation to accelerate growth (more crops/year)
	Rate of assimilation of fertilizer

Plant Health	Disease control
	Insect control
Food Preservation	Prevention of spoilage by mold and bacteria
	Growth inhibition
New Product Development	Mutations

The experiments in this chapter are intended to demonstrate some of these applications. These are less sophisticated than the practical forms, but the principles are the same.

The student may proceed at an individual rate through this area.

NOTE: Experiment 9-3 in the health services chapter might also be considered an applied biology experiment. You may wish to do it as part of this chapter.

EXPERIMENT 8-1

NUCLEAR CLOCKS

INTRODUCTION:

How old is a rock? How old is man? How old is the earth? These are questions that man has attempted to answer for many years. Yet the only reliable method of measuring very long intervals of time is quite new. Radioactive atoms change themselves into other atoms at regular and constant rates. If something gradually transforms itself into something else at a known rate, and if all products of the activity are preserved in some kind of a closed system, then it is theoretically possible to calculate the time elapsed since the process started. In this case, a closed system is a system in which the parent material radioactively decays into its daughter products and nothing new is added or removed.

In practice, the best example of a nuclear clock is the decay of carbon-14. You may have heard about carbon dating being used to determine the age of fossils. Carbon-14 has a half-life of about 5700 years.

In this experiment, we shall attempt to model this procedure but will use an isotope with a much shorter half-life.

MATERIALS NEEDED:

Cesium-137/Barium-137^m minigenerator
2 planchets
Scaler, G-M tube, and timer
Clock with sweep second hand
Sheet of semi-log paper
Safety tray and liner
Ringstand and buret clamp
Plastic gloves
Unknown sample prepared by instructor

PROCEDURE & INTERPRETATIONS:

PART I

Clamp the G-M tube in the buret clamp and set the apparatus on the safety tray. Put your planchet under the G-M tube and adjust the height of the tube so it is about 2 cm above the planchet. Take a background count.

Position the Cs-137/Ba-137^m minigenerator so that you can drop the eluant into the planchet. Watch your wristwatch or wall timer until the sweep second hand is on twelve and quickly elute 4 drops into the planchet. Immediately start your scaler and take a one minute count. Record the time that you put the eluant into the planchet. Record the one minute count from your scaler. Wait one minute and take another one minute count. Continue this process for about 15 minutes. Record your data in a table like that shown in FIGURE 8-1.

Time drops put in planchet ____________

Time (min.)	c/m	Corrected c/m
0.5		
2.5		
4.5		
6.5		
8.5		
10.5		
12.5		
14.5		

FIGURE 8-1

Notice the time we are recording in our table is the time that has elapsed since our sample was placed into the planchet. Therefore, we will record our first count as 0.5 minutes, which would be the average count between the time we started and the time the first count ended. We then wait one minute before we take a one minute count; hence, we are taking the count between the second and third minute of elapsed time. Thus, we record this as an average count between the second and third minute or 2.5 minutes. This process is continued until about 15 minutes of time has elapsed.

PART II

Use a different planchet and add 4 drops of eluant from the cesium-137/barium-137m minigenerator. Immediately take an initial count and record the time you take it. Determine the corrected c/m.

After an elapsed time of four minutes, take another one minute count. Record and determine the corrected c/m. Repeat the process after a total elapsed time of eight minutes.

Plot these three points on the same semi-log graph paper as you used in Part I. (Remember to plot the points at .5 min., 4.5 min., and 8.5 min.)

Draw the straight line that best fits these three points.

Q1 - How do the two lines on your graph compare?

Q2 - If you would take three counts on another sample of the same material and plot on your graph paper, how do you think this line would compare with the other two?

Obtain an unknown sample from your instructor. This sample contains the same material as your other samples. Your instructor will tell you the initial count which he obtained on the sample just after elution.

Take another count on the sample and record the time at which it was taken. Correct both counts for background radiation. On the same sheet of graph paper with your other two lines, plot the initial corrected count at time 0.5 minutes. (The count that the instructor gave you.)

Q3 - How do you think the line for this plot would extend from this point? Draw a straight line from this point in the direction you think it would extend. Locate the corrected count which you took on the sample on this line.

Q4 - How much time elapsed between the original elution and this point?

Q5 - Using your graph and the time you took your count, determine when you think your instructor eluted the minigenerator into the planchet.

Q6 - Ask your instructor and then record the time when the minigenerator actually was eluted.

Q7 - How does your prediction compare with the actual time of elution?

As a plant grows, the carbon in its structure is obtained from carbon dioxide in the air. A certain percent of naturally occurring carbon dioxide contains radioactive carbon-14. Suppose a piece of wood is found which contains only one-fourth of the carbon-14 which would be expected in a newly formed piece of wood.

Q8 - How long ago did the piece of wood grow?

EXPERIMENT 8-2

FOOD PRESERVATION BY IRRADIATION

INTRODUCTION:

All foods begin to spoil in one way or another immediately after they have been harvested. If this could be prevented by irradiation, the economic value of such a process would be immeasurable. Man has long searched for the best method to preserve his food. The best method can be described as one which (a) has a lasting effect, (b) does not change the natural color, and (c) does not change the natural flavor. Let's determine whether or not exposure to gamma radiation will actually preserve food.

MATERIALS NEEDED:

3 slices of bread
Clear plastic sandwich bags with fold lock top
Label tape
Gammator

PROCEDURE & INTERPRETATIONS:

Slice bread into ½ sections, 4 to be used as controls, 4 to be irradiated 24 hours and 4 to be irradiated over a weekend. Moisten each ½ slice of bread in water and, handling it very gently, slide it across the top of the laboratory table. Each piece of bread can now be placed in a separate clear plastic sandwich bag. Tuck the bread into a far corner of the bag, fold over the lock top, and fold the bag so that it's about the same size as the bread. Irradiate 4 of the bread samples in the Gammator for a 24-hour period. Irradiate another 4 samples of bread over the weekend. Store the controls in an appropriate place assigned by your instructor. After irradiation, store the other samples in the same place. At the conclusion of 5-7 days, examine and compare the controls with the irradiated bread.

Q1 - How did the bread irradiated for 24 hours compare with the control? How did the bread irradiated for 72 hours compare with the control?

Q2 - Compare the bread irradiated for 24 hours with the bread irradiated for 72 hours.

Q3 - Would the bread which was irradiated over the weekend be safe to eat?

Enzymes or microorganisms such as bacteria, mold and yeast contribute to food spoilage. Spoilage is merely the chemical breaking down of the molecules of food. The two causes of spoilage, organisms and enzymes, are closely interrelated because the organisms will chemically manufacture the enzymes that causes the chemical breakdown. Large doses of radiation will kill the organisms, or change the structure of enzymes, that would cause decay or spoilage. Thus, large doses of radiation will cause sterilization and this is called radiation sterilization. Smaller doses of radiation can cause partial killing of the organisms, and this is called radiation pasteurization.

Q4 - What foods do you know of which are pasteurized? What method is used?

Q5 - Can you think of places where radiation pasteurization or sterilization might be used?

EXPERIMENT 8-3

GROWTH INHIBITION

INTRODUCTION:

Food preservation takes more than one form. One involves killing molds which grow on foods. A different problem arises, however, when foods like onions and potatoes sprout. Can radiation help in preventing such growth?

MATERIALS NEEDED:

Gammator
6 onion sets
6 beakers
Round toothpicks

PROCEDURE AND INTERPRETATIONS:

Arrange the onions into two groups of three onions. Three will be used as controls and will not be irradiated. Irradiate the other three for 24 hours in the Gammator.

Prepare the onions to be partially immersed in water as follows. Choose a beaker of appropriate size to match the size of the onion. Insert 4 round wood toothpicks into the onion side about one-fourth of the way down. See FIGURE 8-2. Fill the beaker with water. Place the onion in the beaker so that the tip is in the water, and the toothpicks support the onion by extending over the edge of the beaker.

Change water daily, and observe for root tip growth. Record your observations.

FIGURE 8-2

Q1 - Describe differences (if any) in the root tip development of each group.

Q2 - Would either group grow into plants which are radioactive?

Q3 - Describe how this system could be used to extend the storage time of onions. Would onions treated this way be radioactive?

EXPERIMENT 8-4

DIFFUSION

INTRODUCTION:

Will molecules pass through a membrane from a region of higher concentration to a region of lower concentration?

The cell, the fundamental unit of life, is surrounded by a membrane. The cell requires food and oxygen and must discharge its wastes. The cell is normally surrounded by a liquid medium. If the concentration of the liquid in the cell is different than the concentration of the liquid outside, will material pass through the cell membrane?

To attempt to answer these questions, we will set up a model of this system. To simulate the cell membrane, we will use dialysis tubing. Inside this tubing we will put a solution of slightly higher concentration than the liquid we will put on the outside. Can we tell if there is any movement through the membrane? In order to answer this question, we will use a radioisotope on the inside of the dialysis tube.

MATERIALS NEEDED:

G-M tube, scaler and timer
Minigenerator Sr90/Y90
Dialysis tubing (size 36, 1 1/8" diameter) 15 cm long
Ringstand and clamp
Tray and liner
2 pipettes (1 ml) with propipetter
2 beakers (15 ml)
Rubber bands
Beaker (100 ml)
Graph paper
Plastic ring that will fit the dialysis tubing

PROCEDURE & INTERPRETATIONS:

Soak the piece of dialysis tubing in water to soften it and separate the plastic layers so it will be like a tube. Tie a knot in one end of the tubing to make it water tight. Pour in 10 ml of water to determine the length needed to hold 10 ml of liquid. Cut the tubing about 2 cm above this level and throw the water away. Fit the plastic ring into the open end of the tube, like a collar, and secure it with a rubber band. See FIGURE 8-3. Test your solution for possible leaks using distilled water.

If the bag shows no leaks, empty the bag. Place the ringstand on your tray. Clamp the collar to the ringstand with a clamp. Adjust the height of the bag so that the knot is about 10 cm from the tray.

Wearing plastic gloves, elute the minigenerator with 10 ml of eluate. Collect the eluant in the dialysis bag.

By adjusting the clamp, suspend the filled dialysis bag in a 100 ml beaker so that the knot just touches the bottom. See FIGURE 8-4.

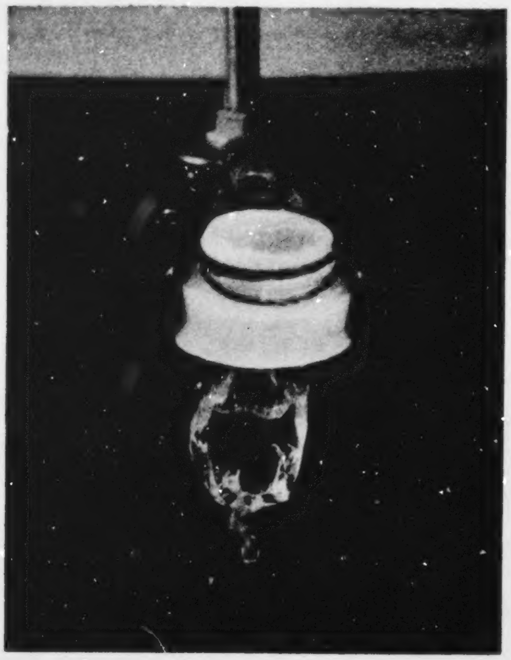


FIGURE 8-3

FIGURE 8-4

Add distilled water to the beaker until the liquid level is the same in the beaker as it is in the bag. Clamp the bag to maintain it in this position.

Record the background count.

Label the pipettes so one can always be used to pipette liquid from the dialysis bag and the other liquid from the beaker. Don't switch them for the rest of the experiment.

Clamp the G-M tube with a buret clamp so that the end window of the tube is facing down. Using the labeled pipette, withdraw 1 ml from the contents of the dialysis tubing. Place the liquid in a 15 ml beaker. With the other pipette withdraw 1 ml from the liquid outside the dialysis tubing. Place in the second 15 ml beaker. Record the activity of each sample. Adjust the G-M tube so its window is about 1 to 2 cm from the liquid. See FIGURE 8-5.

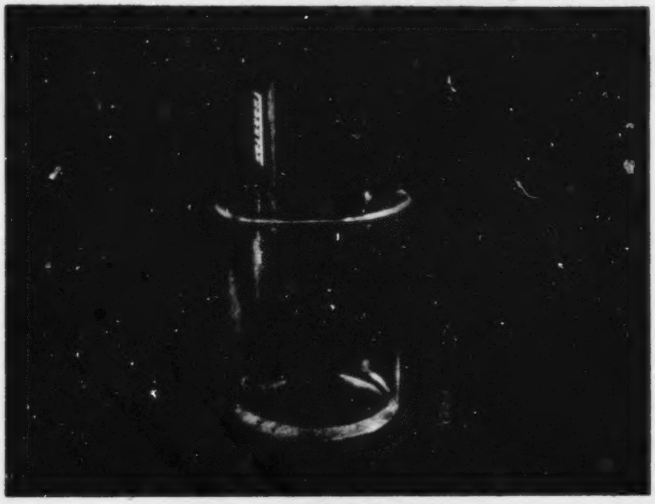


FIGURE 8-5

Make sure that the liquid does not touch the G-M tube. Keep the G-M tube positioned so all subsequent counts will be made from the same distance. Record the time that each count was taken. Return each sample to its original source. Rinse the beakers with water in the "hot" sink and dry for future use.

At convenient intervals during the day, repeat this process. Record both the time and the activity observed for each sample. Try to keep the period between samples about 1 hour.

Allow the apparatus to stand overnight and check the activity of the samples.

Record your data in a table with the following headings:

		Solution in Bag		Solution in Beaker	
Time	Elapsed time (hrs.)	Activity (c/m)	Corrected c/m	Activity (c/m)	Corrected c/m

Plot both sets of data on the same piece of graph paper. Use elapsed time (hours) on the horizontal axis and corrected c/m on the vertical axis.

Q1 - Did Yttrium-90 pass through the membrane? How do you know?

Q2 - Which solution had the greatest initial concentration of Yttrium — that inside the bag or outside the bag?

This process which involves physical passage of molecules through a membrane from a region of higher concentration into a lower concentration is called diffusion.

Q3 - Did all of the Yttrium-90 pass through the membrane? How do you know?

Q4 - Compare your two curves. Predict how the activity of the two solutions would compare after a long period of time.

Q5 - What do you think is happening to the concentration of the two solutions as the experiment proceeds?

Q6 - Assume that the contents of the outer container were replaced with distilled water each time samples were taken. What would happen?

Q7 - Propose a hypothesis concerning the structure of the dialysis tubing to explain the passage of the radioactive molecules through it.

Q8 - Considering that molecules are in constant motion, your model of the tubing in Q7, and your answer to Q4, why does the concentration of Yttrium reach a point where it stays the same on both sides of the tubing?

Q9 - List several conditions that would tend to increase the amount of diffusion taking place through a membrane.

Q10 - If our model of the cell is correct, how can the cell get oxygen, food and remove its wastes?

Q11 - Which organ of the body has a moist surface, large area, and thin membranes that would allow oxygen and carbon dioxide diffusion to take place?

EXPERIMENT 8-5

THE UPTAKE OF CARBON-14 IN A VERIGATED LEAF

INTRODUCTION:

Carbon dioxide is used by a plant in a process called photosynthesis. Green plants convert tremendous amounts of solar energy into chemical energy, providing food and fuel for man. Photosynthesis is a complex reaction involving many steps, but the end result can be summarized by the following word equation:

$$\text{Carbon dioxide} + \text{water} \longrightarrow \text{oxygen} + \text{sugar}$$

$$6\,CO_2 + 6\,H_2O \longrightarrow 6\,O_2 + C_6H_{12}O_6$$

In this experiment, we shall attempt to determine which part of a verigated leaf uses carbon dioxide. To do this, we will introduce carbon dioxide containing an isotope of carbon, carbon-14. This isotope is radioactive and thus we should be able to detect its presence in the leaf.

MATERIALS NEEDED:

Sodium carbonate containing carbon-14
Plant with verigated leaves (coleus)
G-M tube and scaler
X-ray film
Developer
Fixer
Syringe
Clear plastic bag large enough to hold the plant
Dilute sulfuric or hydrocholoric acid
2 eye droppers
Small dish (00 crucible)
Ringstand and buret clamp
150 w bulb
Sodium hydroxide solution
Calcium hydroxide solution
Rubber tubing to fit 6 mm glass tubing
Glass tubing (6 mm)
Screw clamp
Aspirator
Scotch tape
Plastic gloves
Electrician's tape
Safety tray and liner
2 hole rubber stopper (6½ or 7)

4 short armed, right angle bent glass tubes
2 long armed, right angle bent glass tubes
Glycerine
Rubber band
2 250 ml erlenmeyer flasks with 2 hole stoppers to fit

PROCEDURE & INTERPRETATIONS:

Work on your safety tray and tape a crucible to the pot of a coleus plant. See FIGURE 8-6. Carefully place the pot, with the crucible attached, inside the plastic bag. Using a razor blade or knife, cut a grooved ring all the way around a large 2 hole rubber stopper. See FIGURE 8-6. Cut the groove near the top of the stopper. Put a short armed, right angle bent glass tube through one hole of the stopper. In the other hole, insert a medicine dropper. Make sure that they are tight. You may want to smear a little glycerine on the glass before you put it through the stopper. Fit the top edge of the plastic bag around the stopper. Use a rubber band to fasten the bag to the stopper by putting the rubber band so that it fits into the groove of the stopper. Make sure it is air tight. Clamp the stopper to a ringstand with a buret clamp. Attach a piece of rubber tubing to the right angle bent glass in the stopper. The rubber tubing should be long enough to reach the table. Place a screw clamp on the rubber tubing near the glass connection and tighten so that the assembly will be air tight. See FIGURE 8-7.

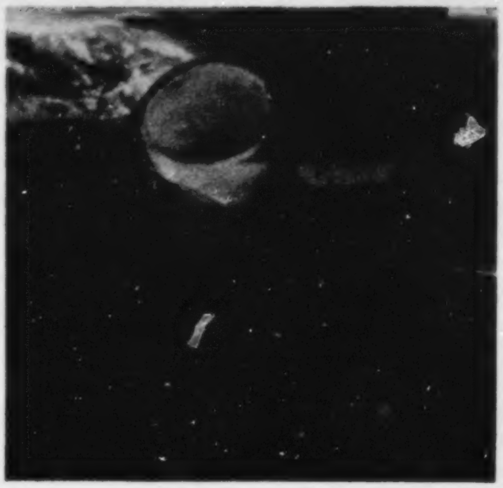


FIGURE 8-6

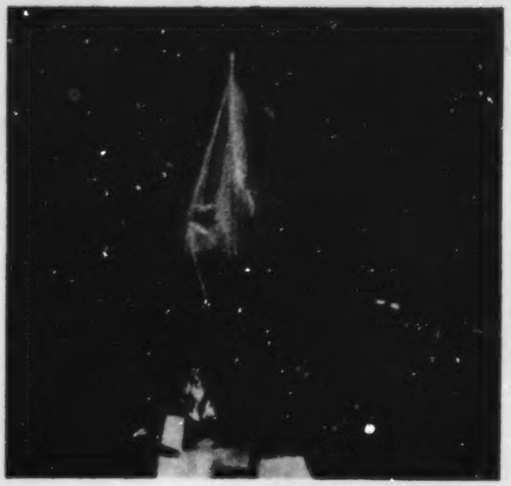


FIGURE 8-7

Cut a small hole through the plastic bag near the crucible, just large enough to fit the glass end of an eye dropper. Fill an eyedropper with dilute acid. Poke the tip of the dropper through the hole and add the acid to the crucible. Add a second dropper of acid in the same manner.

Wearing plastic gloves, fill another eye dropper with sodium carbonate containing carbon-14. (Don't use the same eye dropper.) Insert the dropper through the slit, drop the sodium carbonate into the crucible, and observe. Immediately remove the dropper and seal the hole with tape so that it is air tight. After a few minutes, scan the bag for radioactivity with your G-M tube and scaler. Record your observations.

Q1 - What did you observe when the acid mixed with the sodium carbonate?

Q2 - What gas do you think is given off in this reaction?

Choose one of the large leaves near the crucible and position the light so it shines on the leaf. Allow this apparatus to stand until the next day. Prepare a ventilating system using pieces of rubber tubing, a 10 cm piece of straight glass tubing, and 5 right angle bends, as shown in FIGURE 8-8.

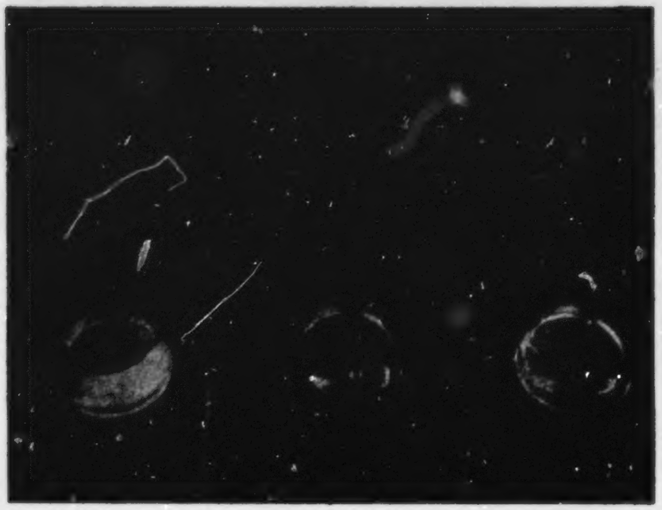


FIGURE 8-8

Put about 150 ml of sodium hydroxide solution in the first two erlenmeyer flasks nearest the plastic bag assembly and an equal amount of calcium hydroxide solution in the other erlenmeyer flask. Note that the intake tube to each flask is below the liquid surface.

Attach your ventilating train assembly to the rubber tube of the plastic bag assembly. Use a piece of rubber tubing to connect the other end of your train assembly to a water aspirator. See FIGURE 8-9.

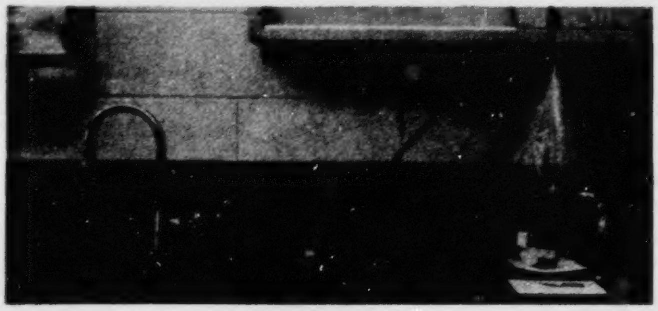


FIGURE 8-9

Slowly turn on the water until bubbles are slowly passing through the flasks and observe. Recall, from other classes, that lime water (calcium hydroxide solution) will turn cloudy in the presence of carbon dioxide. When the plastic bag collapses, take the rubber bulb off the medicine dropper, in the assembly, in order to allow air to flush through the system. This should force dry unused radioactive carbon dioxide through the assembly.

Q3 - Was any carbon dioxide left when the bubbles reached the third flask?

Q4 - Why didn't we just open the bag and take the plant out?

Disassemble the apparatus and wash the erlenmeyer flasks and crucible in the "hot" sink. Cut off the leaf on which you focused the light and check it for radioactivity with the G-M tube. Check two or three parts of the leaf.

Record your observations.

Q5 - Could you observe any radioactivity?

Prepare to make an autoradiograph of a leaf. Either of the following exposure procedures may be followed:

Method 1. Place the leaf on an X-ray packet with the top surface of the leaf turned toward the film. Cover the leaf with a piece of plastic wrap and weight with a book. After 3 days, develop the film using the same technique you used in Experiment 2-1.

Method 2. This procedure is more complex but reduces the exposure time from 3 to 1 day. In a darkroom (no light at all) carefully open the plastic film covering. Insert the leaf inside, on top of the X-ray film, with the top side of the leaf down. Use a piece of electricians' plastic tape to seal the packet so no light will enter. Now you can turn on the light. Weight the film packet with a book to insure close contact between the leaf and the film. After 24 hours, and while working in the dark, remove the leaf and reseal the packet with electricians' tape. Develop the film using the same technique you used in Experiment 2-1.

Q - Which portion of the film was exposed most?

Q - What is the color of this portion of the leaf?

Q - If that portion of the leaf were tested for sugar, would you expect a positive reaction?

Q - Which substance produced contains the carbon-14?

EXPERIMENT 8-6

PHOSPHOROUS UPTAKE IN THE GREEN PLANT

INTRODUCTION:

Commerical fertilizers are usually rated with three numbers such as 5 - 10 - 5. The first number indicates the percent of nitrogen, the second the percent of phosphorous, and the third the percent of potash (Potassium). In this experiment we shall investigate the effect of one of these elements, phosphorous, on a plant. Is phosphorous taken up by a plant? If so, how and where is it used? If a plant is deficient in phosphorous will it take it up at a faster rate than a plant which has a sufficient amount of phosphorous? In this experiment, we shall attempt to answer these questions.

MATERIALS NEEDED:

Phosphorous-32
Autoradiograph supplies
2 tomato plants
Plastic gloves
Safety tray
Ringstand
2 buret clamps
4 test tubes, 10 mm x 100 mm
Eye dropper
Nutrient solution A (with phosphorous)
Nutrient solution B (without phosphorous)
Cotton
Light source - suitable for plant growth
Razor blade

PROCEDURE & INTERPRETATIONS:

PART I: EFFECT OF PHOSPHOROUS ON PLANT GROWTH

Using a buret clamp, attach two test tubes to a ringstand. Add about 2 ml of nutrient A to one test tube and 2 ml of nutrient B to the other test tube. Label the test tubes.

Choose two similar tomato plants and wash the soil from their roots. Be careful not to damage the tender roots. Place the tomato plants in test tubes A and B. Be sure that the roots are in the nutrient solution. If they are not add a little more solution. Insert a small cotton plug into the mouth of each test tube to serve as a stem support. It will also reduce evaporation. See FIGURE 8-10.

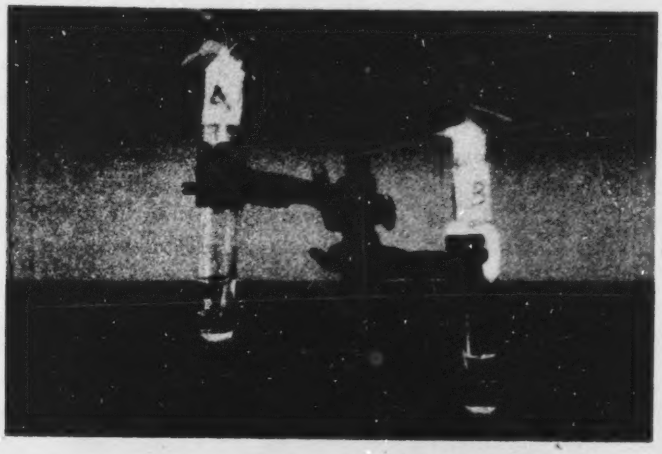


FIGURE 8-10

Place both plants under a light source for 24 hours. At the end of 24 hours study the plants and record your observations.

Q1 - Is phosphorous necessary for a healthy plant?

PART II: UPTAKE OF PHOSPHOROUS-32

Place the ringstand and plant assembly on your lined safety tray. Wearing plastic gloves carefully add 1 ml of phosphorous-32 to each test tube. Replace the cotton plugs. Place both plants under a light source for at least 24 hours. At the end of 24 hours record your observations.

Q2 - How do the plants compare?

Wearing gloves, remove the plants from the solution and blot them dry with paper towels. Using a razor blade, cut the root system from each plant. Arrange each plant on a film packet. (Label) You may have to cut the plant to get an autoradiograph of a complete plant. Cover the plant and packet with plastic wrap. Place a book on top of the wrap and leave undisturbed until the next class period. Dispose of the radioactive wastes in the proper manner.

After 24 hours develop the film for each plant using the techniques of Experiment 2-1. Be sure to key the film to the plant before you remove it from the plastic container. Examine your autoradiographs by placing them side-by-side against a white background.

Q3 - Did either or both of the plants take up the phosphorous-32?

How does phosphorous get from the solution to the various parts of the plant? The movement of materials through a plant is called translocation.

Q4 - Does the distribution of phosphorous seem to be even or localized?

Q5 - If it is concentrated, where does it seem to be the most heavily concentrated?

Q6 - Which plant took up the most radioactive phosphorous?

Q7 - What determines the amount of an element a plant will take up?

EXPERIMENT 8-7

PHOSPHOROUS & PHOTOSYNTHESIS

INTRODUCTION:

Molecules of phosphates are fundamental to the chemistry of all green plants.

In photosynthesis, green plants produce sugar as they use carbon dioxide, water and the energy from light.

Later, the plant will use the sugar it manufactured. The sugar may be used directly as a source of food energy, or it can be chemically transformed to another substance essential to the well being of the plant. Phosphate molecules are essential to both these processes.

MATERIALS NEEDED:

Phosphorous-32
Autoradiograph supplies
Coleus plant
250 ml erlenmeyer flask
400 ml beaker
1 ml pipette and propipetter
Light source
Cotton
Razor blade
Aluminum foil
Plastic wrap
Safety tray & liner
Plastic gloves

PROCEDURE & INTERPRETATIONS:

Obtain a cutting from a coleus plant. Trim off the lower leaves so the end of the stem will reach the bottom of a 250 ml erlenmeyer flask. Pour about 150 ml of water into the flask. Place the end of the stem in a beaker of water. Under water cut off about 1 cm of the stem. Keep this end of the stem under water until you are ready to transfer the plant to the 250 ml erlenmeyer flask.

Wearing plastic gloves and working over a safety tray, use the pipette to add 0.5 ml of phosphorous-32 to the water in the 250 ml erlenmeyer flask. Transfer the plant to the flask containing phosphorous-32. Place a wad of cotton in the mouth of the flask to act as a stem support. See FIGURE 8-11.

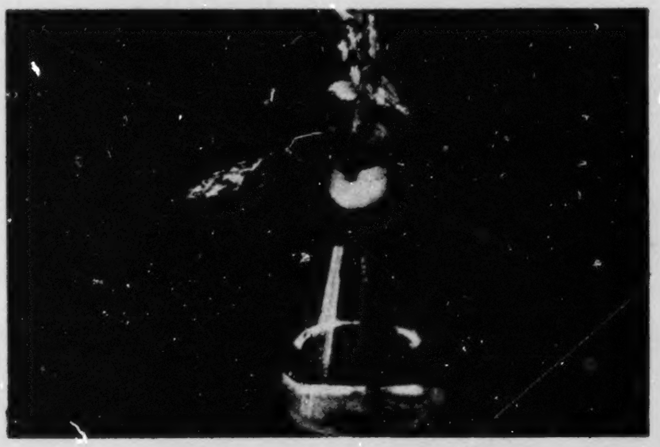


FIGURE 8-11

Choose 2 pairs of leaves on the plant. Select a small pair similar in size near the top (2 young leaves) and a larger pair similar in size near the bottom (2 older leaves). Carefully cover one leaf from each pair with aluminum foil to exclude all light.

Expose the plant to light until the next class period.

The next class period remove the pair of upper (young) leaves from the plant. Carefully remove the aluminum foil from the covered leaf and cut an identifying notch in the leaf. Repeat the process for the older leaves and identify the one that was in the dark.

Position the leaves on a film packet. (It may take two packets if they will not fit on one.) Cover the leaves with plastic wrap and place a book on top of them.

Discard your radioactive wastes in the proper manner.

The next class period develop the film using the techniques of Experiment 2-1.

Remember to use identifying pin holes so you will know the location of the leaves after developing. Place the film on a white piece of paper for observation.

Q1 - Which leaves show the highest concentration of phosphorous?

Q2 - Compare the phosphorous concentration of the leaves in the dark with those in the light.

Q3 - Is phosphorous uptake related to photosynthesis?

Q4 - Compare the phosphorous concentration in the old and young leaves. If there is a difference, suggest a possible reason.

EXPERIMENT 8-8

COLORED LIGHT AND PHOTOSYNTHESIS

INTRODUCTION:

Green plants use the energy of light, for the most part, in the synthesis of glucose. Glucose is an extremely important material. Light is essential for its production in any great quantity.

White light is a mixture of wave lengths representing different colors. You probably have looked at light passing through a prism and have seen that white light is made up of various colors. The shortest wave lengths are violet, slightly longer ones are blue, then green, yellow, orange, and finally red. Do all of these wave lengths have the same efficiency in the production of glucose?

In this experiment, we shall grow aquatic green plants in water that contains carbon-14 dioxide ($^{14}CO_2$). Recall that carbon-14 is radioactive. We can control the wave lengths of light that the plants will receive by wrapping the test tubes in colored cellophane. After a period of time we can remove the plant samples and determine the amount of carbon-14 that they have incorporated. The amount of carbon-14 incorporated will be used to compare the efficiences of various wave lengths of light.

MATERIALS NEEDED:

Carbon-14 ($Na_2{}^{14}CO_3$)
5 aquatic plant tips (such as elodea)
Colored cellophane: red, green, and blue
Light source
Boiled tap water or distilled water
Safety tray & liner
Plastic gloves
5 test tubes (25 x 200 mm) with stoppers to fit
Forceps
250 ml beaker
400 ml beaker
Aluminum foil
G-M tube and scaler

PROCEDURE & INTERPRETATIONS:

Cut 5 tips of the aquatic plant to approximately half the length of the test tube. Pour 250 ml of boiled tap water or distilled water into a 400 ml beaker. Submerge the tips and place in total darkness overnight. Wrap the test tubes with 2 layers of colored cellophane as follows:

Tube 1 - red

Tube 2 - green

Tube 3 - blue

Tube 4 - No wrappings, white light

Tube 5 - Aluminum foil

Pour 130 ml of boiled tap water (or distilled water) into a 250 ml beaker. Wearing plastic gloves and working over a safety tray add 20 μc of radioactive sodium carbonate to the solution in the flask. Pour 25 ml of radioactive solution in each of the test tubes. Remove the plants from the dark and add one to each test tube. Stopper the test tubes. See FIGURE 8-12.

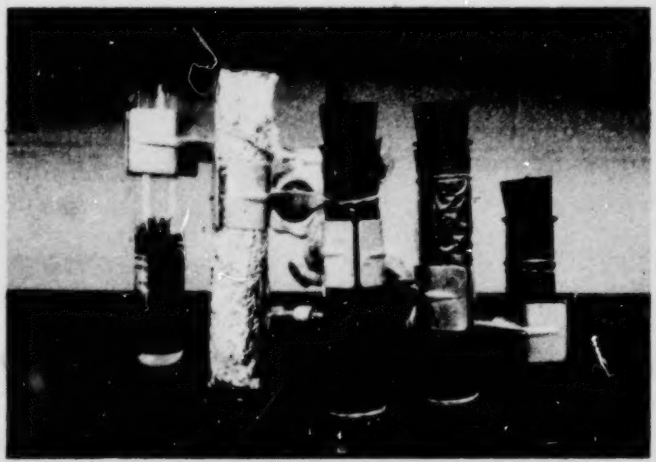


FIGURE 8-12

Place the plants so that they will be in the light. Leave for 24 or more hours.

Wearing plastic gloves and working over a safety tray, use a forceps to remove each plant. Wash each plant separately in tap water. After washing, place plants on the safety tray liner for air drying. Be sure to label the plants so you know from which test tube they came. Clean all glassware that contains radioactive carbon-14 according to the previously discussed procedure.

Center the G-M tube over the plant tip about 1 cm away. See FIGURE 8-13.

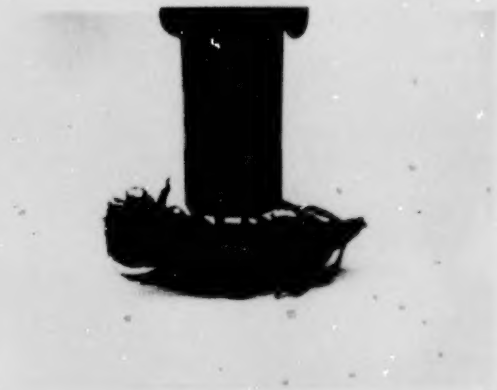


FIGURE 8-13

Take a count on each sample and record. Determine the corrected count for each.

Q1 - For which color was there the greatest $^{14}CO_2$ absorption?

Q2 - For which was there the least?

Q3 - How did the $^{14}CO_2$ absorption of the plant in the white light compare with those in colored light?

Q4 - How did the $^{14}CO_2$ absorption of the plant that received no light (aluminum foil) compare with the others?

Q5 - Do different colored lights (different wave lengths) affect the efficiency of photosynthesis?

PROCEDURE & INTERPRETATIONS:

Cut 5 tips of the aquatic plant to approximately half the length of the test tube. Pour 250 ml of boiled tap water or distilled water into a 400 ml beaker. Submerge the tips and place in total darkness overnight. Wrap the test tubes with 2 layers of colored cellophane as follows:

Tube 1 - red

Tube 2 - green

Tube 3 - blue

Tube 4 - No wrappings, white light

Tube 5 - Aluminum foil

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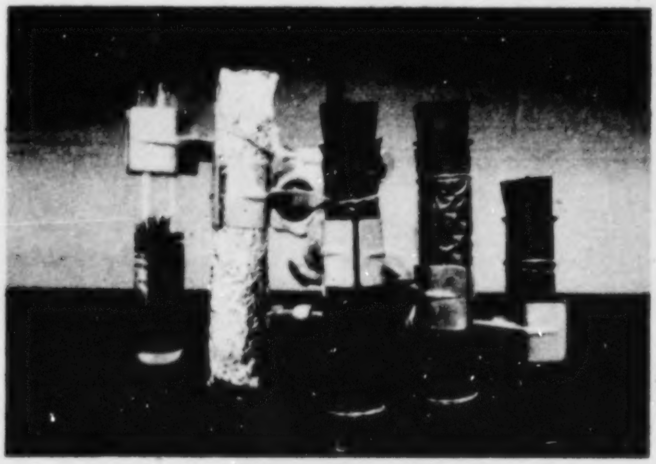

FIGURE 8-12

Place the plants so that they will be in the light. Leave for 24 or more hours.

Wearing plastic gloves and working over a safety tray, use a forceps to remove each plant. Wash each plant separately in tap water. After washing, place plants on the safety tray liner for air drying. Be sure to label the plants so you know from which test tube they came. Clean all glassware that contains radioactive carbon-14 according to the previously discussed procedure.

Center the G-M tube over the plant tip about 1 cm away. See FIGURE 8-13.

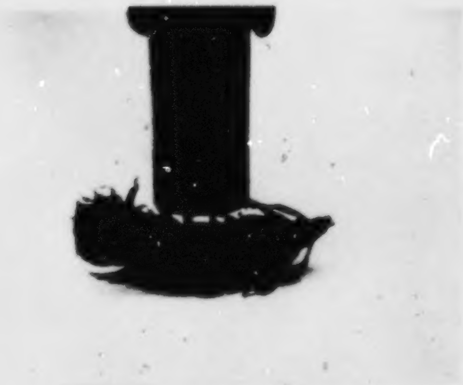

FIGURE 8-13

Take a count on each sample and record. Determine the corrected count for each.

Q1 - For which color was there the greatest $^{14}CO_2$ absorption?

Q2 - For which was there the least?

Q3 - How did the $^{14}CO_2$ absorption of the plant in the white light compare with those in colored light?

Q4 - How did the $^{14}CO_2$ absorption of the plant that received no light (aluminum foil) compare with the others?

Q5 - Do different colored lights (different wave lengths) affect the efficiency of photosynthesis?

EXPERIMENT 8-9

EFFECT OF LOW DOSE RADIATION ON PLANT GROWTH

INTRODUCTION:

Can plant growth be affected by low doses of radiation? In this experiment we will attempt to determine whether low doses of radiation will either retard or stimulate plant growth.

MATERIALS NEEDED:

Small vial or other container to hold seeds while being irradiated
Filter paper (3 thicknesses)
10 Petri dishes (11 cm in diameter)
Radish seeds
Label tape
Gammator

PROCEDURES AND INTERPRETATIONS:

Lay the contents of a package of radish seeds on a paper towel. Cull out all those seeds that seem off color (too dark or too light), or that seem particularly large or particularly small. Count out 2 groups of 50 seeds of uniform color and size.

Set one group of 50 seeds aside to be used as the non-irradiated control.

Place the other group of 50 seeds in a small vial. Irradiate this group of seeds for 2 minutes.

Prepare 10 petri dishes by selecting filter paper slightly smaller than the petri dish. When the filter paper is wet, it should fit down smoothly into the bottom of the petri dish. Fill the petri dish with water and press the filter paper smoothly into the lower part of the dish. The paper should be completely saturated with water. Drain off the excess water.

Place 10 seeds, evenly spaced, down the center of each petri dish. (On the filter paper.) Use 5 dishes for the control and 5 for the irradiated seeds.

The petri dishes can be covered now and properly labeled with label tape.

Store in a convenient place. Each petri dish should be moistened each day, probably using two eye droppers of water for each dish.

On the 7th day, measure the total length. At this time, there might be tiny seed leaves. If they have been stored in the dark, these leaves will not be green. Measure the leaf, stem, and root portion together and record to the nearest whole millimeter.

Construct a data table. On the top, list "growth" in the first column and "percent germination" in the second column. On the side, list "control" and "irradiated (2 min.)"

Calculate the average growth and percent germination for each of the groups. Complete the data table.

Q1 - How did 2 minutes of irradiation affect plant growth?

~~Q2 -~~ How did 2 minutes of irradiation affect seed germination?

Q3 - How could low dose radiation help the farmer in the production of certain foods?

At least one company is now selling irradiated grass seed. The beneficial effect of low dose radiation is called the 102% effect. Interestingly enough, the results are sometimes quite startling.

The flour beetle, tribolium confusium, with which you worked in the LD-50 lab in Chapter 3 is an example of this. His life expectancy is increased about 30% by a dose of 3,000 rads delivered in rates of up to 10 rads per minute. The explanation for this effect is unknown. Conceivably it could arise from the reduction of infection or it might be due to a physiological repair of damage. Irradiation of rice seeds has in some instances been used to increase the number of crops per season. It seems obvious from these examples that irradiation can be a benefit to many by increasing the growth rate of plants that are economically valuable to man.

CHAPTER IX

HEALTH SERVICES

Of all the peace-time uses of nuclear energy, health and medicine is probably the most glamorous. Radio-pharmaceuticals, as they are called, were first used on humans in 1936. Today there are over 100 different radioisotopes which may be used for health purposes.

There are three basic uses for radio-pharmaceuticals; diagnosis of disease, treatment of disease, and study of body functions. In the diagnosis of disease, there is a rapidly increasing use of radio-pharmaceuticals in a process called organ scanning. Organ scanning is a visualization of internal structures not visible in X-ray photographs.

The unique property that is offered by radio-pharmaceuticals is radiation. Therefore, radioiosotopes may be used in diseases where physicians see the need to destroy abnormal cells. This may be accomplished by injecting into the blood stream the appropriate radioisotope which will settle in the desired location.

Another way of treating disease is by injecting radio-pharmaceuticals directly into certain body cavities where localized radiation acts directly on abnormal tissue, and thus, spares the patient the damaging effects of external radiation on normal surrounding tissue.

Physicians often use radio-parmaceuticals to study functions of organs such as the kidneys, the liver, the red blood cells, and the gastrointestinal tract. They can determine normal and restricted blood flow and the pumping capacity of the heart. Blood volume of the patient can also be determined.

From these three uses of radio-pharmaceuticals has come a new technique which may have numerous applications. This new technique is referred to as "outside the body" testing. As the name implies, the tests may be performed outside the body by taking a sample of the patient's blood. Thus the patient is not exposed to radiation.

By doing the following experiments, you can develop a better feeling for these techniques. You may proceed at your own rate through this area.

EXPERIMENT 9-1

BRAIN SCAN

INTRODUCTION:

In Experiment 6-1, the usefulness of radioisotopes as tracers was introduced. In medical applications, radioisotopes are sometimes introduced into the body. Once inside the subject, the location of the tracer is then determined and plotted. This is normally done with special recording equipment working with radiation detectors called scintillation counters. The counters sweep back and forth over the entire surface of the area being surveyed. This process is called scanning. Can abnormalities of the human brain be located by this method?

MATERIALS NEEDED:

G-M tube
Scaler or count rate meter
Figure of head to be surveyed
Timer

PROCEDURE & INTERPRETATIONS:

The figure of a head that has been provided by your instructor has already been treated. This simulates a patient who has already received a tracer. It is your job to determine where the tracer is now located. The model you are working with has a grid marked on the head. This will help you locate and plot the areas of intensified activity. Reproduce the grid of the head on a sheet of graph paper.

It has been found that brain tumors and most other mass lesions are much more permeable to certain isotopes than normal brain tissue. This means that areas of high activity ("hot spots") tell where the growth is located. Using the equipment provided and your grid, determine and sketch the tumor location on the drawing of the head. See FIGURE 9-1.

FIGURE 9-1

Q1 - In what area of the head is the tumor apparently located? (Use grid coordinates of the mask to describe your answer.)

Q2 - The brain scan you just completed was that of a side view. What other views, if any, would you want to take to more precisely locate the tumor?

Q3 - The method you just used was rather time consuming. Suggest a system which would speed up the scanning process.

Q4 - What are the advantages of using the scanning method?

EXPERIMENT 9-2

RENEL OR KIDNEY SCANNING

INTRODUCTION:

NOTE: Before doing this experiment, do Experiment 9-1.

In the last experiment, you conducted a simulated brain scan. Areas of the brain which were abnormal appeared as hot spots on the scan. Can a similar technique be used to investigate kidney disorders? The kidney scan is a very useful tool, for it not only tells if the kidneys are functioning normally, but shows the location of potential problems.

MATERIALS NEEDED:

Kidney models with grid layout
G-M tube and scaler
Graph paper for drawing kidney activity

PROCEDURE & INTERPRETATIONS:

Set up and follow the same procedure as in the brain scan. After completing the scan of the kidneys, shade in the areas of highest activity with a pencil. Compare the scan you just obtained with the scan of normal functioning kidneys. See FIGURE 9-2.

Normal Kidney Scan

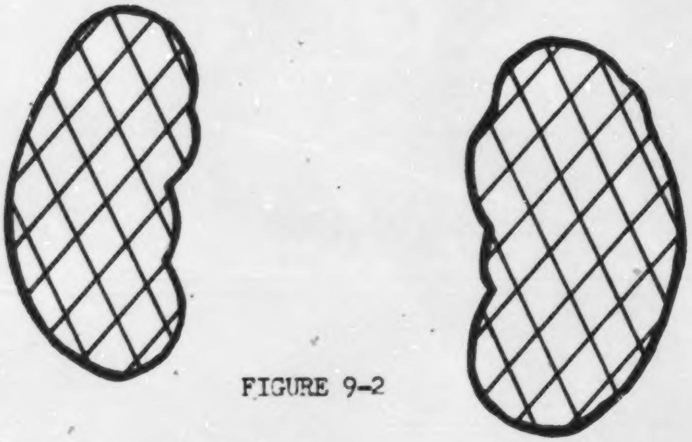

FIGURE 9-2

Q1 - How do the two scans compare?

In the brain scan, abnormalities appeared as "hot spots" on the scan.

Q2 - In the kidney scan, how do abnormalities appear?

By using different types of tracers, doctors can determine the type of abnormality in addition to its location. This technique where "cold spots" indicate the abnormality is also used in lung and liver areas.

EXPERIMENT 9-3

CHEMICAL UPTAKE IN FROGS

INTRODUCTION:

Among the uses of radioisotopes in health is the study of body functions. Can we determine which organs absorb specific chemicals? In this experiment you will determine which organs in a frog absorb phosphorous-32.

MATERIALS NEEDED:

Frog
Phosphorous-32 solution
Cotton cloth
Chloroform
Planchets
Dissecting materials
2 ml syringe & needle
Safety tray & liner
Plastic gloves
G-M tube and scaler

PROCEDURE & INTERPRETATIONS:

Inject a frog with 1 ml (2 μc) of phosphorous-32 solution and then place the frog into a one liter beaker which contains about 1 cm of water. Cover the beaker so the frog cannot escape. Place in a refrigerator if convenient.

After 1 day, drain the beaker and drop the cotton cloth soaked with chloroform over the frog in the beaker and replace the cover. After the frog has been immobilized for several minutes, pin it firmly to a dissecting board, ventral side up. (NOTE: have the dissecting board on a safety tray and wear plastic gloves.)

Beginning between the hind legs, cut through the skin in a median straight line forward to the lower jaw. Cut the skin away from the ventral surface and lay to one side.

Beginning just in front of the hind legs, cut forward through the muscle wall of the abdomen to the breast bone. Carefully cut through the muscle of the chest region, exposing two small bones that connect the breast bone to the shoulder. Slip the point of the scissors under these bones, as near the shoulder as possible, and cut them in two. Lift up the breast bone and free it from the underlying organs by cutting the strips of muscles which connect it with the floor of the mouth. Remove the breast bone from the body, taking care not to disturb the heart and liver below.

Note the heart is in a thin, membranous sac. Carefully remove this sac. (Leave the heart in place.) Insert a needle and injection syringe into the largest visible blood vessel, and withdraw 1 ml blood. Place this on a planchet for counting.

The lungs lie on the right and left sides. See FIGURE 9-3. Remove the lungs for counting. (NOTE: before placing all organs on planchets for counting, rinse them in clear water and blot dry with paper toweling to remove external blood.)

The large and red lobed organ posterior to the heart is the liver. Remove it for counting.

Projecting from under the liver on the left side of the body is the stomach. Cut at the head end of the stomach to remove it from the esophagus. Lift the stomach. Note that it is connected to the small intestine, and the small intestine to the large intestine. Remove these three organs as one, for counting.

Remove the heart for counting.

Carefully remove the skin from the hind legs. Add this to the skin removed from the abdomen for counting.

Separate tho hind legs from the trunk. Carefully remove the muscle from the legs. Place the bones and muscle in separate planchets for counting.

Locate the fat body at the head end of the reproductive glands. Remove it for counting.

FROG

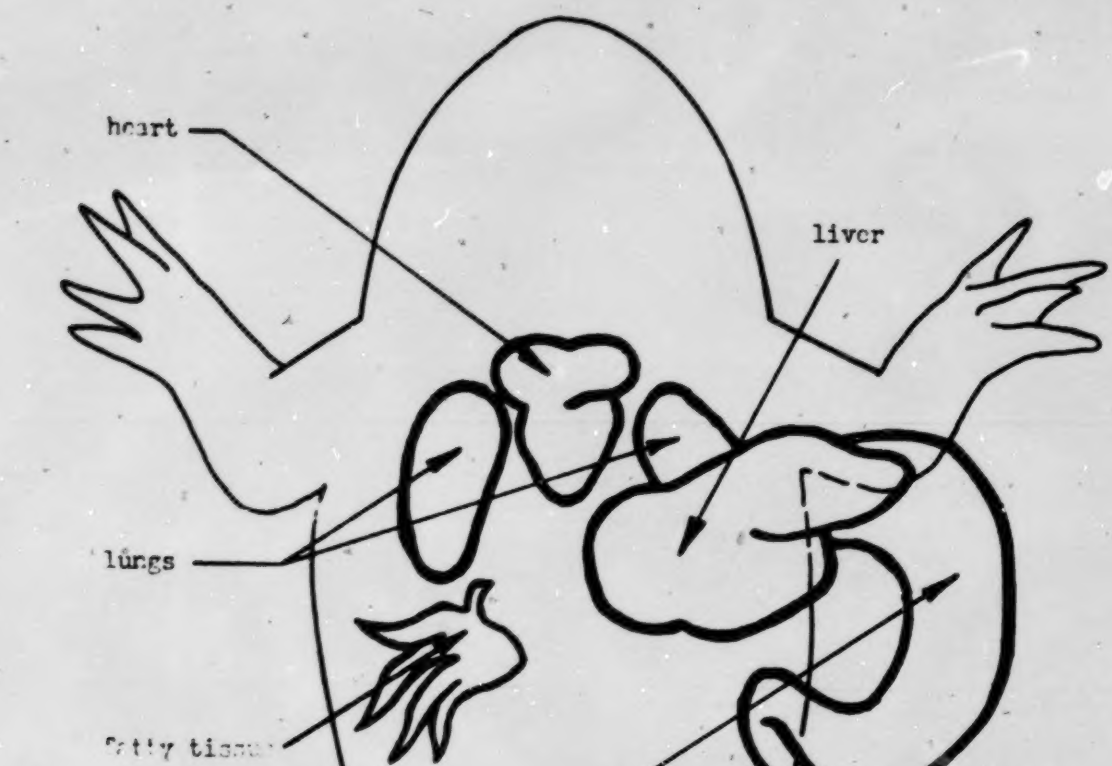
heart
liver
lungs
fatty tissue
stomach
large intestine

FIGURE 9-3

Carefully record all of your data in a table similar to FIGURE 9-4

ORGAN	WEIGHT OF ORGAN	ACTIVITY c/m	CORRECTED ACTIVITY c/m	UPTAKE c/m/mg
Liver				
Heart				
Lung				
Stomach & Intestines				
Bone				
Fat				
Skin				
Muscle				

FIGURE 9-4

Q1 - Which organ had the greatest uptake of phosphorous-32?

Q2 - Which organ had the least uptake?

Q3 - How could a procedure of this type be used in the study of body functions?

EXPERIMENT 9-4

BLOOD VOLUME

INTRODUCTION:

The importance of knowing the volume of blood plasma in an individual can be illustrated by the following situation. Suppose an accident victim is brought unconscious into the emergency room of a hospital. The doctors assume he has lost a considerable amount of blood - but how much? If they give him an unnecessary transfusion, serious complications can develop. If they do not give him a needed transfusion, he may die from loss of blood. His blood volume must be determined.

How can the volume of his blood be determined? We will attempt to answer this question using a hollow rubber animal or doll, rather than a live animal.

MATERIALS NEEDED:

Model (hollow rubber animal)
Minigenerator (Sn 113/In 113^{m})
G-M tube and scaler
Ringstand and buret clamp
3 15 ml beakers
Hypodermic syringe
Plastic gloves
Safety tray and liner

PROCEDURE & INTERPRETATIONS:

Elute the minigenerator with 30 drops of eluant, collecting the eluate in a 15 ml beaker. Add about 1 ml of water and mix thoroughly. Using the hypodermic syringe, transfer 1.0 ml of the solution to a 15 ml beaker. This solution will be used as a control, so put it in a safe place until needed later.

Fill the animal with water which will be our animals' "blood". Using the same syringe used to measure the control solution, carefully inject 1.0 ml of the radioactive solution into the model. This work should be done over a safety tray in case of any spills.

Shake the model a few minutes to simulate blood circulation. Now using the same syringe as before, remove 1.0 ml of "blood". Transfer the "blood" to a 15 ml beaker. Determine the activity in counts/minutes of the control and the blood sample using identical counting conditions. See FIGURE 9-5.

FIGURE 9-5

Record your data in a table similar to FIGURE 9-6.

Activity of 1.0 ml injected control	c/m
Activity of 1.0 blood removed	c/m
Volume of injected control	1.0 ml
Volume of blood removed	1.0 ml
Total "blood" volume	ml

FIGURE 9-6

This experiment is based on the dilution principle. The radioactive solution will spread evenly throughout the "blood stream". By comparing the activity of the diluted sample with the activity of the undiluted sample (control) and knowing their volumes, the total volume may be calculated.

The volume of "blood" in ml for the model can be determined by using the following equation:

$$V' = \frac{AV}{A'}$$

where A = the activity of the control

A' = the activity of the blood removed

V = the volume of the injected liquid

V' = the total volume of the model's blood

Q1 - What is your calculated value for the "blood" volume of the model?

Q2 - Does the half-life of the radioactive solution affect the results of this experiment? Explain.

Q3 - What difficulties could arise if a radioisotope such as phosphorous-32 were used in an actual patient?

Q4 - Does the volume injected have to be the same as the volume of blood removed?

Pour the contents of the model into a graduated cylinder.

Q5 - How does the volume measured with the graduated cylinder compare with your answer to Q1?

Ask your instructor to partially refill the model to simulate a blood deficiency. Using the same procedure, determine the volume of "transfusion" necessary to bring the "blood" volume to normal.

Q6 - What volume did you find necessary?

Add this volume to the model to check your accuracy. (Use a hypodermic syringe.)

EXPERIMENT 9-5

A MODEL FOR THERAPEUDIC UPTAKE

INTRODUCTION:

One means of treating certain diseases is by the injection of radiopharmaceuticals into the blood streams of patients. How can this technique be of use? The purpose of this experiment is to show a model of this technique. It is based upon the fact that certain organs or tissues have affinities for certain radioisotopes.

MATERIALS NEEDED:

G-M tube
Ringstand and small rings to hold funnels
Scaler
Minigenerator (Sn 113/In 113^m)
Test tube
4 15 ml beakers
2 funnels
Filter paper
Small amount of sodium hydroxide solid
Safety tray & liner
Plastic gloves

PROCEDURE & INTERPRETATIONS:

Place 20 ml of distilled water in a test tube. Elute about 4 ml from the minigenerator directly into the same test tube. (Work on a safety tray and wear plastic gloves.) Mix thoroughly. Divide the solution into equal parts and place in two 15 ml beakers. Determine and record the activity of the solution in each beaker. Set up the apparatus as shown in FIGURE 9-7.

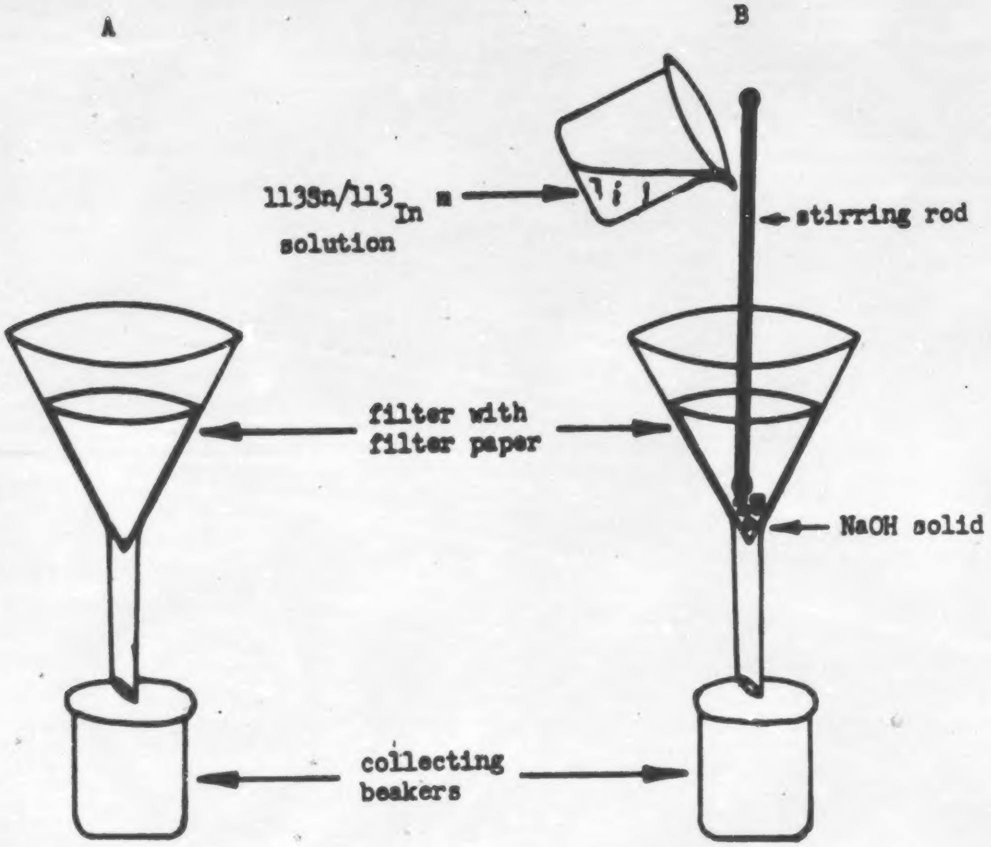
A
B
113Sn/113In m
solution
stirring rod
filter with
filter paper
NaOH solid
collecting
beakers

FIGURE 9-7

Place 5 pellets of sodium hydroxide on the filter paper in one of the filters. Slowly pour the solution into each of the filters. Wait for 3 minutes and then add 10 ml of distilled water to each filter, allowing the wash water also to be collected in the beakers. Remove the filter papers from the funnels and find the activity at the center of each. Measure and record the activity of each of the collecting beakers. A sample data table is shown in FIGURE 9-8.

	A		B	
	Activity (cpm)	Corrected Activity (cpm)	Activity (cpm)	Corrected Activity (cpm)
Initial Reading				
Filter Paper (Precipitate)				
Collecting Beaker (Filtrate)				

FIGURE 9-8

Q1 - Which filter paper showed the highest count?

Q2 - If the sodium hydroxide represents a tumor, what type of radiation would be best suited for destroying the tumor? (α , β, or γ) (assume the isotope you choose has an affinity for the tumor.)

Q3 - Why would the type of radiation you chose for Q2 be best?

Q4 - What advantages would this means of treating a diseased organ have over treatment from external beams of radiation?

EXPERIMENT 9-6

OUTSIDE BODY TESTING

INTRODUCTION:

Are there medical uses for radioisotopes that do not involve the introduction of a radioisotope into the body? Physicians have discovered that the chemical make up of red blood cells is affected by the behavior of the thyroid gland. They have also found that carefully manufactured and treated sponges can indicate abnormal blood cell make up. This in turn can indicate the presence of a normal, overactive, or underactive thyroid gland.

MATERIALS NEEDED:

G-M tube and scaler
Ringstand and buret clamp
Samples to be tested: A, B, C, & D
4 uptake sponges
10 ml graduated cylinder
4 test tubes
Stirring rod
4 planchets
Forceps
Safety tray & liner
Plastic gloves

PROCEDURE & INTERPRETATIONS:

Samples A, B, C, & D represent chemical extractions from the red blood cells of 4 patients. The sponges have been identically treated with a certain radioisotope. An abnormally high or low removal of radioactivity from the sponge, by the blood cell extraction, can indicate an abnormally functioning thyroid gland.

Place the four uptake sponges in separate planchets and record the activity of each. Keep track of which reading goes with which sponge. Be sure the geometry of the counting system is the same in every measurement. See FIGURE 9-9. These readings will be later used in calculating the percent uptake.

FIGURE 9-9

Place one of the sponges and 8 ml of sample A in a test tube. With the stirring rod, immerse the sponge to make sure it becomes completely saturated with the solution. Wait approximately 3 minutes. Press on the sponge again and then pour off the liquid into a marked test tube. Take the sponge from the test tube and remove as much of the liquid remaining in the sponge as possible. Place the sponge in a planchet and determine its activity, keeping the same geometry as before.

Repeat the procedure for samples B, C, and D. Record your data in a table similar to FIGURE 9-10.

	ACTIVITY BEFORE SOAKING c/m	ACTIVITY AFTER SOAKING c/m
Sponge 1	(A)	
Sponge 2	(B)	
Sponge 3	(C)	
Sponge 4	(D)	

FIGURE 9-10

Once all the readings of before and after the soaking are recorded, the percent uptake may be calculated using the following formula:

$$\% \text{ uptake} = \frac{\text{Activity Before} - \text{Activity After}}{\text{Activity Before}} \times 100\%$$

Q1 - What is the percent uptake of each for the four samples? List the samples in descending order according to their percent uptake.

Q2 - Which patients would you suspect of having abnormally functioning thyroid glands?

APPENDIX A

SAFETY IN THE LABORATORY

1. Don't eat, drink, or apply cosmetics in the laboratory.

2. Don't pipette by mouth.

3. Wash your hands after working with radioisotopes, check with a survey meter, and repeat until they are "clean".

4. Always work with liquid radioisotopes in a safety tray with a liner. (Liner should have an absorbent surface and a waterproof backing.)

5. Wear plastic or rubber gloves and laboratory coats while working with liquid radioisotopes.

6. Wear film badges and dosimeters and log your exposure before leaving the laboratory.

7. Use tweezers when handling planchets or other radioactive specimen.

8. Use radiation warning labels to mark all containers or specimen which are radioactive.

9. Dispose of all solid radioactive wastes in the special trash can marked "CONTAMINATED."

10. Dispose of liquid radioactive wastes in the labeled beakers supplied by your instructor.

11. Monitor your work area throughout each experiment, involving radioactive liquids, especially if contamination is suspected.

12. Report all spills of radioactive materials to your instructor immediately. Also report all cuts or other wounds to your instructor.

PERIODIC CLASSIFICATION OF THE ELEMENTS

(BASED ON $C^{12} = 12.0000$)

Light Metals		Heavy Metals										Nonmetals					
I A	II A	III B	IV B	V B	VI B	VII B	VIII B			I B	II B	III A	IV A	V A	VI A	VII A	VIII A
1 H 1.00797																	2 He 4.0026
3 Li 6.939	4 Be 9.0122											5 B 10.811	6 C 12.01115	7 N 14.0067	8 O 15.9994	9 F 18.9984	10 Ne 20.183
11 Na 22.9898	12 Mg 24.312											13 Al 26.9815	14 Si 28.086	15 P 30.9738	16 S 32.064	17 Cl 35.453	18 Ar 39.948
19 K 39.102	20 Ca 40.08	21 Sc 44.956	22 Ti 47.90	23 V 50.942	24 Cr 51.996	25 Mn 54.9380	26 Fe 55.847	27 Co 58.9332	28 Ni 58.71	29 Cu 63.546	30 Zn 65.37	31 Ga 69.72	32 Ge 72.59	33 As 74.9216	34 Se 78.96	35 Br 79.904	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.905	40 Zr 91.22	41 Nb 92.906	42 Mo 95.94	43 Tc 97	44 Ru 101.07	45 Rh 102.905	46 Pd 106.4	47 Ag 107.868	48 Cd 112.40	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.9044	54 Xe 131.30
55 Cs 132.905	56 Ba 137.34	57 TO 71	72 Hf 178.49	73 Ta 180.948	74 W 183.85	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.09	79 Au 196.967	80 Hg 200.59	81 Tl 204.37	82 Pb 207.19	83 Bi 208.980	84 Po 209	85 At 210	86 Rn 222
87 Fr 223	88 Ra 226.05	89 TO 103															

Lanthanide series	57 La 138.91	58 Ce 140.12	59 Pr 140.907	60 Nd 144.24	61 Pm 145	62 Sm 150.35	63 Eu 151.96	64 Gd 157.25	65 Tb 158.924	66 Dy 162.50	67 Ho 164.930	68 Er 167.26	69 Tm 168.934	70 Yb 173.04	71 Lu 174.97
Actinide series	89 Ac 227	90 Th 232.038	91 Pa 231	92 U 238.03	93 Np 237	94 Pu 244	95 Am 243	96 Cm 247	97 Bk 247	98 Cf 251	99 Es 254	100 Fm 253	101 Md 256	102 No 253	103 Lw 257

APPENDIX C

International Atomic Weights

Element	*Symbol*	*Atomic number*	*Atomic weight*	*Element*	*Symbol*	*Atomic number*	*Atomic weight*
Actinium	Ac	89	227*	Mercury	Hg	80	200.59
Aluminum	Al	13	26.9815	Molybdenum	Mo	42	95.94
Americium	Am	95	243*	Neodymium	Nd	60	144.24
Antimony	Sb	51	121.75	Neon	Ne	10	20.183
Argon	Ar	18	39 948	Neptunium	Np	93	237*
Arsenic	As	33	74.9216	Nickel	Ni	28	58.71
Astatine	At	85	210*	Niobium	Nb	41	92.906
Barium	Ba	56	137.34	Nitrogen	N	7	14.0067
Berkelium	Bk	97	247*	Nobelium	No	102	253*
Beryllium	Be	4	9.0122	Osmium	Os	76	190.2
Bismuth	Bi	83	208.980	Oxygen	O	8	15.9994
Boron	B	5	10.811	Palladium	Pd	46	106.4
Bromine	Br	35	79.904	Phosphorus	P	15	30.9738
Cadmium	Cd	48	112.40	Platinum	Pt	78	195.09
Calcium	Ca	20	40.08	Plutonium	Pu	94	244*
Californium	Cf	98	251*	Polonium	Po	84	209*
Carbon	C	6	12.01115	Potassium	K	19	39.102
Cerium	Ce	58	140.12	Praseodymium	Pr	59	140.907
Cesium	Cs	55	132.905	Promethium	Pm	61	145*
Chlorine	Cl	17	35.453	Protactinium	Pa	91	231*
Chromium	Cr	24	51.996	Radium	Ra	88	226.05
Cobalt	Co	27	58.9332	Radon	Rn	86	222*
Copper	Cu	29	63.546	Rhenium	Re	75	186.2
Curium	Cm	96	247*	Rhodium	Rh	45	102.905
Dysprosium	Dy	66	162.50	Rubidium	Rb	37	85.47
Einsteinium	Es	99	254*	Ruthenium	Ru	44	101.07
Erbium	Er	68	167.26	Samarium	Sm	62	150.35
Europium	Eu	63	151.96	Scandium	Sc	21	44.956
Fermium	Fm	100	253*	Selenium	Se	34	78.96
Fluorine	F	9	18.9984	Silicon	Si	14	28.086
Francium	Fr	87	223*	Silver	Ag	47	107.868
Gadolinium	Gd	64	157.25	Sodium	Na	11	22.9898
Gallium	Ga	31	69.72	Strontium	Sr	38	87.62
Germanium	Ge	32	72.59	Sulfur	S	16	32.064
Gold	Au	79	196.967	Tantalum	Ta	73	180.948
Hafnium	Hf	72	178.49	Technetium	Tc	43	97*
Helium	He	2	4.0026	Tellurium	Te	52	127.60
Holmium	Ho	67	164.930	Terbium	Tb	65	158.924
Hydrogen	H	1	1.00797	Thallium	Tl	81	204.37
Indium	In	49	114.82	Thorium	Th	90	232.038
Iodine	I	53	126.9044	Thulium	Tm	69	168.934
Iridium	Ir	77	192.2	Tin	Sn	50	118.69
Iron	Fe	26	55.847	Titanium	Ti	22	47.90
Krypton	Kr	36	83.80	Tungsten	W	74	183.85
Lanthanum	La	57	138.91	Uranium	U	92	238.03
Lead	Pb	82	207.19	Vanadium	V	23	50.942
Lawrencium	Lw	103	257*	Xenon	Xe	54	131.30
Lithium	Li	3	6.939	Ytterbium	Yb	70	173.04
Lutetium	Lu	71	174.97	Yttrium	Y	39	88.905
Magnesium	Mg	12	24.312	Zinc	Zn	30	65.37
Manganese	Mn	25	54.9380	Zirconium	Zr	40	91.22
Mendelevium	Md	101	256*				

*The mass number of the isotope with the longest known half-life.

APPENDIX D

HALF-LIFE OF SELECTED RADIOISOTOPES

m = minutes   h = hours   d = days   y = years

Element	Symbol	Half-Life
Barium	$^{137}_{56}Ba$	2.6 m
Carbon	$^{14}_{6}C$	5730 y
Cerium	$^{144}_{58}Ce$	285 d
Cesium	$^{130}_{55}Cs$	30 m
Cesium	$^{137}_{55}Cs$	30 y
Cobalt	$^{60}_{27}Co$	5.26 y
Indium	$^{113m}_{49}In$	100 m
Iodine	$^{131}_{53}I$	8.1 d
Phosphorous	$^{32}_{15}P$	14.3 d
Plutonium	$^{239}_{94}Pu$	2.44×10^4 y
Plutonium	$^{241}_{94}Pu$	14.3 y
Praseodymium	$^{144}_{59}Pr$	7.2 m
Radium	$^{226}_{88}Ra$	1620 y
Radon	$^{222}_{86}Rn$	3.82 d
Strontium	$^{81}_{38}Sr$	29 m

Stontium	$^{90}_{38}\mathrm{Sr}$	28 y
Tin	$^{113}_{50}\mathrm{Sn}$	118 d
Uranium	$^{235}_{92}\mathrm{U}$	7.13×10^{8} y
Uranium	$^{238}_{92}\mathrm{U}$	4.51×10^{9} y
Yttrium	$^{90}_{39}\mathrm{Y}$	64.2 h

APPENDIX E

USING SEMI-LOGARITHMIC GRAPH PAPER

MATERIALS NEEDED:

1 sheet of regular (rectangular coordinate) graph paper
1 sheet of 2 cycle semi-logarithmic graph paper
Paper and pencil

DIRECTIONS:

Cover the lower part of this page with a blank sheet of paper. Slide the sheet down the page until you have uncovered Question 1. On a separate sheet of paper, follow the instructions until you have answered Question 1. Slide the blank sheet down to the next section and check your answer. If your answer is correct, proceed to Question 2 and continue in the same fashion, checking each answer before going on to the next question. If you answer a question incorrectly, reread until you understand the correct answer. Then proceed to the next question.

The data to the right shows how some quantity, Y, changes with time:

Time (hr)	Y
0	9200
5	7250
10	5600
15	4350
20	3400
25	2600
30	2000
35	1550
40	1200
45	930
50	720
55	550
60	425
65	330
70	250

Answer Check	Question
	1. On a regular piece of graph paper, plot the above data. Plot Y on the vertical axis and time on the horizontal axis. Does Y change to a constant rate with respect to time?
Answer 1: No, If it were changing to a constant rate, the line would be straight.	2. During what 5 hour interval did Y change the most?
Answer 2: During the first 5 hours.	3. From your graph, at what time did Y have a value of 6,000?

Answer 3: Between 8.5 and 9.0 hours	4. At what time was the value of Y 600?
Answer 4: Around 53 or 54 hours.	5. Which of these values was easiest to determine from your graph?
Answer 5: The value at 6000 was probably easier because the graph is steeper at that point and it is in Y values.	6. Now look at a piece of semi-logarithmic graph paper. What differences do you notice in the vertical scale and the horizontal scale?
Answer 6: The spacing on the vertical scale varies, while the spacing on the horizontal scale is constant.	7. The vertical scale is called a logarithmic scale. This particular scale is called a 2 cycle logarithmic scale because it goes through the 1 - 9 number sequence twice. The decimal point can be placed anywhere. If the 1—— at the bottom of the page is called 10, what is the value of the 1—— at the middle of the page?
Answer 7: 100	8. What is the value of the 1—— at the top of the page?
Answer 8: 1000	9. Does every vertical space represent the same amount?
Answer 9: No, the spaces at the top of the graph represent a larger amount.	10. Now set up a graph on the semi-log graph paper. (It is called semi-log paper because the logarithmic scale is used on only one axis. Full logarithmic paper has a logarithmic scale on both axes.) On this graph you are to plot the same data as before. To be able to plot the maximum Y value (9200), the 1—— at the top of the page should represent what number?
Answer 10: 10,000	11. What value does one vertical space at the top of the page represent?
Answer 11: 100	12. What value does one vertical space at the bottom of the page represent?
Answer 12: 5	13. Now plot your data points on the graph and draw in a smooth line that best fits the line?

Answer 13: Straight	14. What are some of the advantages of this graph over the one which you plotted on regular graph paper?
Answer 14: 1. Easier to draw in line 2. Easier to read for small value of Y. 3. Requires less data points to be able to draw in line.	15. Using this graph, answer the same questions asked earlier: a. At what time did Y have a value of 6000? b. At what time did Y have a value of 600? c. Which value was easiest to read?
Answer 15: a. Between 8.5 and 9.0 hr. b. About 53.5 hours. c. They were equally easy to read because the slope of the line is at the same angle. (Although smaller differences in Y can be read for the small numbers—for example a difference of 5 units can be easily read at the bottom of the Y scale but not at the top)	16. To get a better idea of how the logarithmic scale changes, make small marks beside the vertical scale numbers at each of the following numbers; 10,000; half of 10,000 (5000); half of 5000 (2500); half of 2500... continuing until you reach the bottom of the scale. How does the space between the marks compare?
Answer 16: The spaces are equal although each space represents a different amount.	17. For a comparison, mark the same points on your other graph. (regular graph paper) How does the spacing between these marks compare?
Answer 17: It decreases as you go down the page.	18. Which graph is easiest to read for small values of Y?
Answer 18: The semi-log graph.	19. Now refer to your semi-log graph. How long did it take for the value of Y to decrease to half its original value?
Answer 19: About 13.7 hr.	20. How long did it take for the value of Y to be cut in half again?
Answer 20: At about 27.4 hr., which is an additional 13.7 hours.	21. How long do you <ins>predict</ins> for the value of Y to be cut in half again?
Answer 21: If the same pattern continues it should take another 13.7 hours.	22. Check the graph. Was this prediction true?

Answer 22: Yes	23. How would you say the value of Y changes with time?
Answer 23: Every 13.7 hr. the value of Y is cut in half. In general, for equal units of time the value of Y decreases to the same fraction of its previous value. It can be said that the value of Y changes by a constant factor for each unit of time.	24. When will the value of Y become zero?
Answer 24: It will never become zero. Every 13.7 hours its value will be cut in half. This could continue forever without reaching zero. Notice that there is no zero on the logarithmic scale.	25. If you know that the data you are plotting decreases by a constant factor for each horizontal unit, how many data points would you need to draw the graph on semi-log graph paper?
Answer 25: Just 2 since the graph will be a straight line and two points will establish a straight line. Plotting a third point as a check would be a good idea, however, if more data were available.	26. If you are to graph data which increases by a constant amount on the vertical axis, (say 3 units) for every change of 1 unit on the horizontal axis, would you plot the data on regular or semi-log graph paper?
Answer 26: Regular graph paper would be best. This data would give a straight line graph on regular graph paper but would give a curve on semi-log paper. Semi-log paper is not the best for all types of graphs—it depends on the data to be plotted.	27. When would you use semi-log graph paper for plotting a graph?
Answer 27: When it appears that the data to be plotted doesn't change at a constant rate but might be changing by a constant factor for each horizontal unit.	END.

GLOSSARY

ABSORBER	Any material that absorbs or diminishes the intensity of ionizing RADIATION.
ACCELERATOR	A machine that imparts high energies to particles which are then used to bombard nuclei.
ALPHA PARTICLE	(Symbol α (alpha) A positively charged particle emitted by certain radioactive materials. It is made up of two neutrons and two protons bound together, hence is identical with the nucleus of a helium atom. It is the least penetrating of the three common types of radiation (alpha, beta, gamma) emitted by radioactive material, being stopped by a sheet of paper. It is not dangerous to plants, animals or man unless the alpha-emitting substance has entered the body.
ATOM	A particle of matter indivisible by chemical means. It is the fundamental building block of the chemical elements.
ATOM SMASHER	An accelerator.
ATOMIC NUMBER	The number of protons in the nucleus of an atom, and also its positive charge. Each chemical element has its own characteristic atomic number.
ATOMIC WEIGHT	The mass of an atom relative to other atoms. The atomic weight of any element is approximately equal to the total number of protons and neutrons in its nucleus.
AUTORADIOGRAPH	A photographic record of radiation from radioactive material in an object, made by placing the object very close to a photographic film. The process is called autoradiography. It is used, for instance, to locate radioactive atoms or tracers in metallic or biological samples.
BACKGROUND RADIATION	The quantity of radiation at a particular place from sources other than those being studied or measured. It may be due to cosmic rays or to radioactive materials found naturally in rock, earth, wood, soil, and similar materials, or it may be stray radiation from reactors, accelerators, or nuclear reactions other than the one being measured.
BACKSCATTER	When radiation of any kind strikes matter (gas, liquid, or solid), some of it may be reflected or scattered back in the general direction of the source.

BETA PARTICLE	[Symbol β (beta)] An elementary particle emitted from a nucleus during radioactive decay, with a single electrical charge and a mass equal to 1/1837 that of a proton. A negatively charged beta particle is identical to an electron. Beta radiation may cause skin burns, and beta-emitters are harmful if they enter the body. Beta particles are easily stopped by a thin sheet of metal, however.
BREEDER REACTOR	A reactor that produces fissionable fuel as well as consuming it, especially one that creates more than it consumes. The new fissionable material is created by capture in fertile materials of neutrons from fission. The process by which this occurs is known as breeding.
CHAIN REACTION	A reaction that stimulates its own repetition. In a fission chain reaction a fissionable nucleus absorbs a neutron and fissions, releasing additional neutrons. These in turn can be absorbed by other fissionable nuclei, releasing still more neutrons. A fission chain reaction is self-sustaining when the number of neutrons released in a given time equals or exceeds the number of neutrons lost by absorption in non-fissioning material or by escape from the system.
CLOUD CHAMBER	A device in which the tracks of charged atomic particles, such as cosmic rays are displayed. It conists of a glass-walled chamber filled with a supersaturated vapor, such as wet air. When charged particles pass through the chamber, they trigger a process of condensation, and so produce a track of tiny liquid droplets, much like the vapor trail of a jet plane. This track permits scientists to study the particles' motions and interactions.
COLLIMATOR	A device for focusing or confining a beam of particles or radiation, such as X-rays.
CONTAMINATION, RADIOACTIVE	Deposition of radioactive material in any place where it may harm persons, spoil experiments, or make products or equipment unsuitable or unsafe for some specific use. The presence of unwanted radioactive matter. Also radioactive material found on the walls of vessels in used-fuel processing plants, or radioactive material that has leaked into a reactor coolant. Often referred to only as contamination.
CONTROL ROD	A rod, plate, or tube containing a material that readily absorbs neutrons (hafnium, boron, etc.), used to control the power of a nuclear reactor. By absorbing neutrons, a control rod prevents the neutrons from causing further fission.

COSMIC RAYS	Radiation of many sorts but mostly protons with very high energies, originating outside the earth's atmosphere. Cosmic radiation is part of the natural background radiation. Some cosmic rays are more energetic than any man-made forms of radiation.
CURIE	(Symbol c or Ci) The basic unit to describe the intensity of radioactivity in a sample of material. The curie is equal to 37 billion disintegrations per second, which is approximately the rate of decay of 1 gram of radium. A curie is also a quantity of any nuclide having 1 curie of radioactivity. Named for Marie and Pierre Curie, who discovered radium in 1898.
CYCLOTRON	A particle accelerator in which charged particles receive repeated synchronized accelerations by electrical fields as the particles spiral outward from their source. The particles are kept in the spiral by a powerful magnetic field.
DAUGHTER	A nuclide formed by the radioactive decay of another nuclide, which in this context is called the parent.
DECAY RADIOACTIVE	Any nuclear change which involves the expulsion of a particle or emission of a gamma ray, or both. Usually involves the spontaneous transformation of one nuclide to another.
DECONTAMINATION	The removal of radioactive contaminants from surfaces or equipment, as by cleaning and washing with chemicals.
DENSITY THICKNESS	A measure of the shielding effectiveness of various materials. Found by multiplying the density of a material by its thickness (usually measured in grams/cm^2.)
DOSE	The total amount of radiation absorbed by matter. Usually measured in rads or rems.
DOSE RATE	The radiation dose delivered per unit time and measured, for instance, in rems per hour.
DOSIMETER	A device that measures radiation dose, such as a film badge or ionization chamber.
ELECTRON	(Symbol e^-) An elementary particle with a unit negative electrical charge and a mass 1/1837 that of the proton. Electrons surround the positively charged nucleus and determine the chemical properties of the atom.
ELUATE	The solution which comes through a minigenerator.
ELUANT	The washing solution which is put into a minigenerator to produce the eluate.

ELUTE	The process of washing the eluant through a minigenerator.
FALLOUT	The material, particularly radioactive substances, which falls to the earth as a result of a nuclear explosion.
FILM BADGE	A light-tight package of photographic film worn like a badge by workers in nuclear industry or research, used to measure possible exposure to IONIZING RADIATION. The absorbed dose can be calculated by the degree of film darkening caused by the irradiation.
FISSION	The splitting of a heavy nucleus into two approximately equal parts (which are nuclei of lighter elements), accompanied by the release of a relatively large amount of energy and generally one or more neutrons. Fission can occur spontaneously, but usually is caused by nuclear absorption of gamma rays, neutrons or other particles.
FUSION	The formation of a heavier nucleus from two lighter ones (such as hydrogen isotopes), with the attendant release of energy (as in a hydrogen bomb.)
GAMMA RAYS	[Symbol γ (gamma)] High-energy, short-wavelength electromagnetic radiation. Gamma radiation frequently accompanies alpha and beta emissions and always accompanies fission. Gamma rays are very penetrating and are best stopped or shielded against by dense materials, such as lead. Gamma rays are essentially similar to X-rays, but are usually more energetic, and are nuclear in origin.
GAMMATOR	A device which produces large doses of gamma radiation to objects placed in its chamber. The area surrounding its radioactive source always remains highly shielded to protect those nearby.
GAUGING	The measurement of the thickness, density or quantity of material by the amount of radiation it absorbs. This is the most common use of radioactive isotopes in industry. Also spelled gaging.
GEIGER-MULLER COUNTER	(G-M tube) A radiation detection and measuring instrument. It consists of a gas-filled (Geiger-Muller) tube containing electrodes, between which there is an electrical voltage but no current flowing. When ionizing radiation passes through the tube, a short, intense pulse of current passes from the negative electrode to the positive electrode and is measured or counted. The number of pulses per second measures the intensity of radiation. It is also often known as Geiger counter; it was named for Hans Geiger and W. Muller who invented it in the 1920s.

GEOMETRY	The arrangement of source and detecting equipment.
GLOVE BOX	A sealed box in which workers, using gloves attached to and passing through openings in the box, can handle radioactive materials safely from the outside.
HALF-LIFE	The time in which half the atoms of a particular radioactive substance disintegrate to another nuclear form. Measured half-lives vary from millionths of a second to billions of years.
HALF-THICKNESS	The thickness of any given absorber that will reduce the intensity of a beam of radiation to one-half its initial value.
HEALTH PHYSICS	The science concerned with recognition, evaluation, and control of health hazards from ionizing radiation.
HOT	Highly radioactive.
ION	An atom or molecule that has lost or gained one or more electrons. By this ionization it becomes electrically charged.
ION PAIR	A closely associated positive ion and negative ion (Usually an electron) having charges of the same magnitude and formed from a neutral atom or molecule by radiation.
IONIZATION	The process of adding one or more electrons to, or removing one or more electrons from, atoms or molecules, thereby creating ions. High temperatures, electrical discharges, or nuclear radiations can cause ionization.
IONIZING RADIATION	Any radiation displacing electrons from atoms or molecules, thereby producing ions. Examples: alpha, beta, gamma radiation, short-wave ultraviolet light.
IRRADIATION	Exposure to radiation, as in a nuclear reactor or a Gammator.
ISOTOPE	One of two or more atoms with the same atomic number (the same chemical element) but with different atomic weights. An equivalent statement is that the nuclei of isotopes have the same number of protons but different numbers of neutrons. Thus, $^{12}_{6}C$, $^{13}_{6}C$, and $^{14}_{6}C$ are isotopes of the element carbon, the subscripts denoting their common atomic numbers, the superscripts denoting the differing atomic weights. Isotopes usually have very nearly the same chemical properties, but somewhat different physical properties.

LETHAL DOSE	A dose of ionizing radiation sufficient to cause death. LD-50 is the dose required to kill within a specified period of time (usually 30 days) half of the individuals in a large group of organisms similarly exposed. The LD-50/30 for man is about 400-450 roentgens.
LINEAR ACCELERATOR	A long straight tube (or series of tubes) in which charged particles (ordinarily electrons or protons) gain in energy by the action of oscillating electromagnetic fields.
MAXIMUM PERMISSIBLE DOSE (MPD)	That dose of ionizing radiation established by competent authorities as an amount below which there is no reasonable expectation of risk to human health, and which at the same time is somewhat below the lowest level at which a definite hazard is believed to exist.
MINIGENERATOR	A miniature radioisotope generator.
MODERATOR	A material, such as ordinary water, heavy water or graphite, used in a reactor to slow down high-velocity neutrons, thus increasing the likelihood of further fission.
MONITOR	An instrument that measures the level of ionizing radiation in an area.
MUTATION	A permanent genetic change in the characteristics of an offspring from those of its parents.
NEUTRON	(Symbol n) An uncharged elementary particle with a mass slightly greater than that of the proton, and found in the nucleus of every atom heavier than hydrogen. Neutrons sustain the fission chain reaction in a nuclear reactor.
NUCLEAR ENERGY	The energy liberated by a nuclear reaction (fission or fusion) or by radioactive decay.
NUCLEAR RADIATION	Radiation from atomic nuclei, including alpha, beta and gamma radiation and neutrons.
NUCLEAR REACTOR	A device in which a fission chain reaction can be initiated, maintained, and controlled. Its essential component is a core with fissionable fuel. It usually has a moderator, a reflector, shielding, coolant, and control mechanisms.
NUCLEONICS	The science and technology of nuclear energy and its applications.

NUCLEUS	The small, positively charged core of an atom. It is only about 1/10,000 the diameter of the atom but contains nearly all the atom's mass. All nuclei contain both protons and neutrons, except the nucleus of ordinary hydrogen, which consists of a single proton.
NUCLIDE	A general term applicable to all atomic forms of the elements. Nuclides are distinguished by their atomic number, atomic weight, and energy state. Some 1400 different nuclides are known.
PARENT	A radionuclide that upon radioactive decay or disintegration yields a specific nuclide (the daughter), either directly or as a later member of a radioactive series.
PIG	A heavily shielded container (usually lead) used to ship or store radioactive materials.
PROTON	An elementary particle with a single positive electrical charge and a mass approximately 1837 times that of the electron. The nucleus of an ordinary or light hydrogen atom. Protons are constituents of all nuclei. The atomic number of an atom is equal to the number of protons in its nucleus.
RAD	(Radiation absorbed dose) The basic unit of absorbed dose of ionizing radiation. A dose of one rad means the absorption of 100 ergs of radiation energy per gram of absorbing material.
RADIATION WARNING SYMBOL	An officially prescribed symbol (a magenta trefoil on a yellow background) which should always be displayed when a radiation hazard exists.
RADIOACTIVITY	The spontaneous decay or disintegration of an unstable atomic nucleus, usually accompanied by the emission of ionizing radiation.
RADIOISOTOPE	A radioactive isotope. An unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation. More than 1300 natural and artificial radioisotopes have been identified.
RADIOLOGY	The science which deals with the use of all forms of ionizing radiation in the diagnosis and the treatment of disease.
RELATIVE BIOLOGICAL EFFECTIVENESS (RBE)	A factor used to compare the biological effectiveness of different types of ionizing radiation.

REM	(Roentgen equivalent man) The unit of dose of any ionizing radiation which produces the same biological effect as a unit of absorbed dose of ordinary X-rays. The RBE dose (in rems) = RBE x absorbed dose (in rads).
ROENTGEN	(Abbreviation r) A unit of exposure to ionizing radiation. It is that amount of gamma or X-rays required to produce 2.083×10^9 ion pairs in 1 cubic centimeter of dry air under standard conditions. Named after Wilhelm Roentgen, German scientist who discovered X-rays in 1895.
SCALER	An electronic instrument for rapid counting of radiation-induced pulses from Geiger counters or other radiation detectors.
SHIELD (SHIELDING)	A body of material used to reduce the passage of radiation.
STABLE	Incapable of spontaneous change. Not radioactive
SURVEY METER	Any portable radiation detection instrument especially adapted for surveying or inspecting an area to establish the existence and amount of radioactive material present.
TRACER, ISOTOPIC	An isotope of an element, a small amount of which may be incorporated into a sample of material (the carrier) in order to follow (trace) the course of that element through a chemical, biological or physical process, and thus also follow the larger sample. The tracer may be radioactive, in which case observations are made by measuring the radioactivity. Tracers also are called labels or tags, and materials are said to be labeled or tagged when radioactive tracers are incorporated in them.
TRANSMUTATION	The transformation of one element into another by a nuclear reaction or series of reactions. Example: the transmutation of uranium-238 into plutonium-239 by absorption of a neutron.
X-RAY	A penetrating form of electromagnetic radiation emitted either when the inner orbital electrons of an excited atom return to their normal state or when a metal target is bombarded with high speed electrons. X-rays are always nonnuclear in origin, but are similar to gamma rays (which are nuclear in origin).